NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

HIGH RESOLUTION MODELING OF A TERRORIST CHEMICAL ATTACK IN AN URBAN AREA

by

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June 1999

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1999	Master's Thesis

4. TITLE AND SUBTITLE HIGH RESOLUTION MODELING OF A TERRORIST CHEMICAL ATTACK IN AN URBAN AREA	5. FUNDING NUMBERS
6. AUTHOR(S) Broadwater, Jeffery D.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution unlimited.	

13. ABSTRACT *(maximum 200 words)*

This thesis demonstrates the use of Janus in Modeling Military Operations Other Than War, MOOTW. Janus has many uses throughout the United States military. Lately, MOOTW have become a major percentage of the U.S. military's efforts. Using Janus to model these operations can help predict casualties, determine if new pieces of equipment make a difference in the operation, and help evaluate "what ifs" in operations. More importantly, conducting a simulation before carrying out an actual exercise saves money and people's time and effort. The threat of a terrorist chemical attack is a very likely event in this day and age as demonstrated by the 1995 chemical attack in a Japanese subway. Current U.S. policy has allocated certain resources to assist local governments in the event of an emergency. Unfortunately, these assets can not immediately respond to a chemical crisis. Time waiting for these assets to arrive must be spent wisely to save lives. Local governments do not all have the same capabilities available to respond to a chemical attack. Using a high resolution combat model such as Janus at the local level will help determine assets that will save lives and money.

SUBJECT TERMS Janus, Sarin, Terrorism, HPAC Model, Military Operations Other Than War, Hypothesis test, Goodness-of-Fit-Test	15. NUMBER OF PAGES 113
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFI- CATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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HIGH RESOLUTION MODELING OF A TERRORIST CHEMICAL ATTACK IN AN URBAN AREA

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN APPLIED MATHEMATICS

from the

NAVAL POSTGRADUATE SCHOOL
June 1999

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ABSTRACT

This thesis demonstrates the use of Janus in modeling Military Operations Other Than War, MOOTW. Janus has many uses throughout the United States military. Lately, MOOTW have become a major percentage of the U.S. military's efforts. Using Janus to model these operations can help predict casualties, determine if new pieces of equipment make a difference in the operation, and help evaluate "what ifs" in operations. More importantly, conducting a simulation before carrying out an actual exercise saves money and people's time and effort. The threat of a terrorist chemical attack is a very likely event in this day and age as demonstrated by the 1995 chemical attack in a Japanese subway. Current U.S. policy has allocated certain resources to assist local governments in the event of an emergency. Unfortunately, these assets can not immediately respond to a chemical crisis. Time waiting for these assets to arrive must be spent wisely to save lives. Local governments do not all have the same capabilities available to respond to a chemical attack. Using a high resolution combat model such as Janus at the local level will help determine assets that will save lives and money.

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ACKNOWLEDGMENTS

I would like to thank Dr. Russell C. Coile, the Disaster Coordinator/Emergency Program Manager of Pacific Grove, California, and Chris Reitenour of the Seaside, California Fire Department for their assistance in answering questions related to dealing with emergency responses. Also, I would like to thank Mary Worth, Community Hospital of the Monterey Peninsula for her input into the development of this thesis. Without their help, assumptions within this thesis would have no value.

Additionally, Mr. David Graves of the Defense Threat Reduction Agency, DTRA, Washington, D.C., for his help understanding the output of the HPAC graphs.

Finally, to my thesis advisor Bard Mansager, for his mentoring and teaching skills. Bard's willingness to mentor and make dry subjects interesting is invaluable. I hope to take these traits into the classroom through my teaching assignment at West Point.

I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to assist local governments in crisis management by showing the capabilities of a high-resolution combat simulation to model Military Operations Other Than War (MOOTW). Because responding to terrorism within the United States is an example of MOOTW, developing the model can also simulate local community actions. The community assets will be the first to respond to the crisis, and therefore local governments must be trained for such an event.

B. BACKGROUND

The threat of a chemical terrorist attack in a populated area is a very real danger to the United States as well as the rest of the world. According to A National Security Strategy for A New Century, [Ref. 1], because of the United States' military and weapons superiority, other nations or terrorist groups may resort to terrorist acts against unsuspecting civilian targets instead of conventional military operations. With today's advanced information technology, terrorists have the ability to collect information rapidly, communicate freely, and gather

materials needed to produce chemical weapons. In the past years, two examples have shown the need for the United States to develop and implement resources to deter this threat. On March 20, 1995 a terrorist group used Sarin gas in the Tokyo subway killing twelve and injuring more than 5,000 people [Ref. 2]. The 1995 Oklahoma City bombing of the Murrah Federal Building shows that terrorism is not just a major city problem, but can happen anywhere and at anytime. These two events show just how vulnerable the United States and the world are to a terrorist attack and chemical weapons.

One of America's reportedly best prepared cities to deal with terrorist attacks, New York City, conducted an exercise similar to the Tokyo subway gassing on April 11, 1995. The results of this no notice exercise were alarming. Not properly assessing the nature of the emergency, fire and rescue personnel responding to the scene became casualties themselves because they did not don their protective masks and protective clothing before rushing to the aid of the victims. On December 7, 1995 in Burbank California, a simulated release of a nerve agent in a hotel revealed the same results. There were 300 dead and 500 injured in this training exercise. According to a <u>News Advisory</u>, [Ref. 2], published by the Chemical and Biological Weapons

Nonproliferation Project; if chemical agents were used in the terrorist attack on the World Trade Center in 1993, the 20,000 people in the building would have been incapacitated within three minutes and dead within six minutes. The accuracy of this statement depends on many factors that are not discussed at this time, but the statement does show what could happen if such weapons were deployed.

Having seen the need for legislation dealing with America's preparation to defend against and defeat a terrorist chemical attack, the Domestic Preparedness Initiative (Public Law 104-201, September 23, 1996) was created. This law is commonly called the Nunn-Lugar-Domenici legislation. This law provides funding for the Department of Defense (DOD) to assist the ability of federal, state, and local emergency workers (first responders) in incidents involving chemical terrorism. Public awareness is the first step in preparing for a chemical attack. Civilians must learn to identify the symptoms the human body experiences during a chemical attack. Not only will this save lives, but also help the initial emergency crews arriving at the location to have a better grasp of the situation and not become casualties themselves. One of the initiatives from this law was to introduce training programs designed to enhance the public's awareness of chemical weapons and

identifying chemical symptoms. Another tool designed to increase awareness is classes designed for city mayors and their councils. The classes will help develop awareness and decision making skills to handle a chemical attack. Unfortunately, making the public aware is a difficult task. Many people find it hard to conceive that a terrorist attack could happen in their city or if it did, that the attack could not be quickly repelled.

Recently, several agencies have formed a union to execute the Domestic Preparedness Program developed by the Department of Defense in 1996. One of the missions of this program is to develop first responder abilities to react to Nuclear, Biological, Chemical (NBC) terrorism. To accomplish this mission, training and mock exercises will occur in 27 cities with a goal of training 120 cities during the next three years [Ref. 3]. Other assets to assist in a terrorist chemical attack are being developed under the Department of Defense Plan for Integrating National Guard and Reserve Component Support for Response to Attacks Using Weapons of Mass Destruction published in January 1998, [Ref. 4]. This plan calls for the development of Rapid Assessment and Initial Detection (RAID) elements in each state or territory. These teams will provide the major capability for the technical Department of Defense support. Some of the

likely tasks that the RAID elements will assist first responders are early assessment and detection of a chemical agent, determining the concentration of the release, and determining the areas to evacuate. The goal is for the first element of the RAID team, the reconnaissance element, to be on site not later than four hours after the request for help is issued.[Ref. 4] This is a major issue, and possibly not achievable, since not all team members will be full-time members of the National Guard or Reserve unit.

Regretfully, many lives can be lost within a four-hour window. In most cases the city and county resources will be the only available assets to respond immediately to a chemical attack when life or death could possibly be a difference of only a matter of minutes. As expected, resources and funding for personnel, training, and equipment are different in each city. Larger cities have larger budgets, and more equipment than smaller cities. The more probable the attack in an area, the more personnel they have trained. Again, as shown in the Oklahoma City bombing, terrorist attacks are not predictable and not just targeted against the world's largest populated areas. Small cities with large tourist populations or locations with a large work time population are possibly as an attractive target to a terrorist as New York, Chicago, Los Angeles, or any

other large metropolis. Maybe these smaller areas are even more of a target since the element of surprise of a chemical attack, and fewer assets and trained personnel to handle the situation would be expected. Because of the unpredictability of a terrorist attack all first responders must train and practice as much as possible. Experience has to be gained in order to achieve confidence in their matter of life or death decision-making skills. Simulations offer a monetarily cheap way to test a city's plan for responding to a chemical attack, and to help acquire priceless experience in decision-making skills.

C. JANUS MODEL

Janus is used primarily as an Army wargaming simulation to model brigade and below sized operations. It was initially used as a nuclear effects simulation model by the Lawrence Livermore National Laboratory of the University of California. Janus is a high resolution, interactive, closed, stochastic, combat wargaming simulation designed to analytically study doctrine, strategy, and weapon system development. Closed means the location of the opposing side is hidden to the other side until a system under that side's control detects the other sides system.[Ref. 5] This makes the user search and find casualties within an area giving the model a more accurate portrayal of what would actually

happen in an emergency operation. The major advantage of Janus is the interaction allowed between the user and the model. The user can make real-time changes in the simulation at any time. This allows the user to see the effects on an operation if it is conducted one way or another. It can also be used non-interactively. This has advantages because it reduces the variance of human decisions made during the exercise. Another advantage of Janus is the ability to create and move icons on actual terrain. The simulation uses digitized terrain from the National Imagery and Mapping Agency (NIMA) to display elevation and vegetation. Different types of roads, buildings, and cities can also be added so the operator's simulation is as accurate to the actual terrain as possible. Because the terrain and urban characteristics of the area are represented within the model, Janus can realistically model movement and visibility. Icons such as victims, fire engines, ambulances, and police vehicles can be added to represent the different participants in the exercise.

As mentioned earlier, Janus primarily simulates force-on-force military operations, but can pay major dividends in helping analyze Military Operations Other Than War. Even though Janus has limited chemical play, the imagination is the only hurdle in what can be modeled and analyzed. Janus

can be used to compare different routes to see which is fastest and how much transportation is needed to most effectively transport casualties. Additionally, questions such as:

- What would happen if a chemical attack occurred at a different location instead of the one expected?
- What would happen if a larger or smaller amount of chemical were used?

These questions can be answered as well as others. The most important advantage of Janus to simulate a chemical attack is its outcome determination capability. This can help medical personnel and hospitals anticipate what they can expect if such an emergency occurred. Also, the simulation can help everyone visualize the total area that would be considered contaminated, and how many people would have to be evacuated. Janus currently is not available in a personal computer program due to the large demand it places on system resource requirements. However, because Janus is used extensively in the Army and Marine Corps, it is available to many communities where other chemical models are not. Enormous benefits would be gained if the military allowed the civilian population access to Janus. If local communities were allowed access to Janus, more community leaders could gain experience through the simulation.

Finally, simulations have the potential to save a large amount of money and time. This saving could then be spent on more equipment and training needed to prepare for a chemical incident.

D. HAZARD PREDICTION AND ASSESSMENT CAPABILTY MODEL (HPAC)

Because of Janus' limited chemical capability, another model's output will be used to supplement this thesis' scenario. HPAC provides a model that can produce an area of the chemical spread based on the historical weather and terrain data of the targeted location. The Defense Threat Reduction Agency, (DTRA) is the proponent of this model. DTRA was formerly known as DSWA, Defense Special Weapons Agency. HPAC can also predict the expected number of casualties within the contaminated area. [Ref. 6] Figure 1 displays a typical output from the HPAC model. The legend in figure 1 displays the expected number of victims for a certain dosage amount. Also, from the graph we can determine where the expected amounts of the chemical will spread within the area. From the graph, the large area represents the threshold amount of the chemical, 1 mg-min/m^3. The smallest oval represents an area where a person would receive a lethal dosage over 100 mg-min/m^3. Dosage rates will be discussed in more detail in Chapter II. Using HPAC's

output strengthens the accuracy of the Janus model. We have valid patterns of the chemical dissipation based on historical weather data. Without this feature, we would have to rely on Janus, which does not allow as many weather factors to be considered.

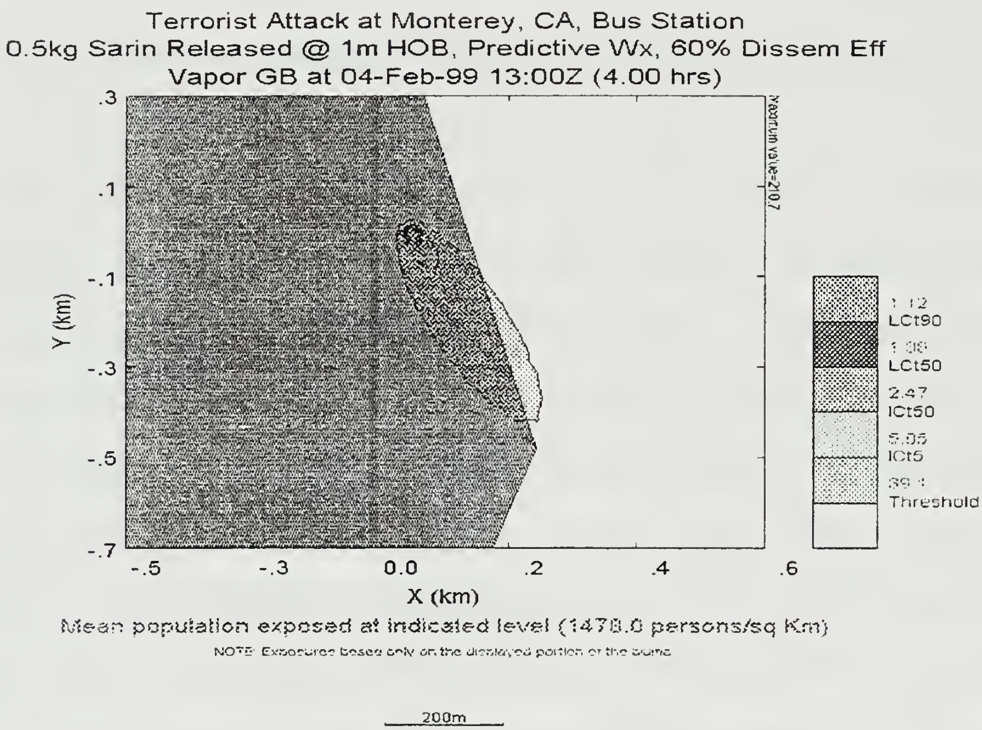

Figure 1. Output from HPAC Model

Having determined the need for a local community response model, we develop a model to solve specific questions of the local response to a chemical attack asked in this chapter. In Chapter II we discuss how we develop a terrorist scenario. Chapter III discusses how we incorporate

the terrorist model into a high resolution model. In Chapter IV we analyze the model's output in an attempt to answer certain questions about the problem. Lastly, in Chapter V we make conclusions and recommendations about how to handle such a horrible event.

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II. TERRORIST SCENARIO DEVELOPMENT

A. SCENARIO OVERVIEW

Realizing that state and federal assets are not expected to arrive at the site of the emergency until four hours after the chemical release is identified, the local emergency response team should establish a generic timeline for planning purposes. This helps all participants in the exercise understand how the local civil emergency response system works and what each participant's role is in the operation. Using the baseline exercise conducted in Pacific Grove, California, [Ref. 7], and discussing the problem with local officials and first responders; the following generic timeline was developed for the model.

Sequence	Start Time	Action	Finish Time	Notes
Event 1	H-hour	Chemical released	H+ 10 min	
Event 2	H+10 min	Symptoms appear/ 911 Called	H+15 min	
Event 3	H+15 min	Police, Fire, Amb arrive confirm release	H+25 min	
Event 4	H+31 min	HAZMAT TM arrives starts to monitor and observe	H+40 min	

Event 5A	H+40 min	Extricate and initial triage of causalities	Rate is 30 sec per person (non-serious). Move as group add 2 min from last victim. Serious rate is 1 min per person. 30 min to move each victim	- 2 rescue personnel required for non-serious patients. - 6 rescue personnel for serious. 2 is absolute min. - 4 rescue personnel needed for litter bearing
Event 5B	H+40 min	Hasty Decon site est.	H+60 min	- Need rescue personnel 12
Event 6	H+60 min	Extra Ambs arrive at decon site. Firefighters gather casualties	H +70 min	-Ensure extra atropine on site.
Event 7	H+60 min	Start Decon	Standard is 12 per hour. 3 per 15 min	
Event 8	H+75 min	Move victims to hospitals	Until complete	-Ensure patient dissemination to various hospitals is understood. Ensure back-up trans is available
Event 8		Chemical most likely dissipated	H+90 min	Max number of firefighters on hand from county(approx. 55)
Event 9		Con't EVAC, Chemical Decon	H+270 min	-Should be working with initial national assets

Table 1. Generic Response Timeline for City Actions in a Chemical Attack "After Ref. [7]"

This timeline will serve as the basis for the event scheduling of the simulation. Since events in an actual exercise have many human factors involved with the sequence of events, the times serve as an event driver for the scenario and should be considered flexible for an actual event. The times and actions of the simulation represent the ideal performance by players in the scenario. Having the players use a different set of parameters and assumptions to exercise decision-making and training techniques would represent actual performance. For example, if firefighters had to search a larger area for victims because they did not know the exact radius of the chemical attack, the reaction times would be slower. In this study the intent was to base the timeline on the most accurate set of parameters and assumptions possible so most of the times are those presented in Reference 7. The chemical event times were derived from current chemical publications in conjunction with local first response leaders, [Ref. 19]. The modeling of these times will be discussed in detail in Chapter III.

Having established a general timeline to follow, the scenario begins with the initial chemical attack. Once the fire department and HAZMAT team have identified and confirmed that an attack in fact occurred, casualties are collected and taken to a decon site for decontamination.

Using values from the established timeline, more emergency assets arrive and assist in the operation. Casualties are moved to the hospital once they have been decontaminated. For this simulation the contaminated area is known precisely. This means the emergency workers know exactly the radius of the chemical spread due to the wind and weather. This represents the best case scenario for determining casualties and where emergency assets are needed. Taking advantage of the "closed" attribute, the simulation can provide variations of the chemical dispersal to allow the participants to practice their decision-making skills. This adds a significant learning capability for the participants since not all communities have the same amount of chemical emergency training. Conducting the simulation can help visualize the "Hot Zone", the suspected contaminated area, to first responders and local authorities who have never experienced such an event. Also, the simulation helps quantify how many assets are needed to evacuate personnel within the contaminated area. The decision-making experience gained from the simulation should reduce the time and effort of the first responders in a real emergency. For example, first responders should develop and train ways not to waste time trying to evacuate a larger non-contaminated area versus identifying and evacuating the actual

contaminated area. Time could then be minimized in a real emergency and hence reduce the number of casualties.

When the primary hospital used in this scenario has reached its maximum caring capacity for patients, additional patients will be taken by ground transportation to adjacent hospitals. Helicopters could be used if the situation dictates. One major drawback in using helicopters within the vicinity of a chemical area is that their rotor blades have the ability to spread the chemical by creating gusts of wind.

B. DEFINITION OF TERMS

Before discussing the specific chemical used in the simulation, certain terms must be defined. For more information on the subjects than what is provided refer to the noted references.

1. Classification of Chemical Agents

Chemical agents can be classified by their physical state, physiological action, or use. For example, a chemical agent's physical state is a gas, liquid, or solid. Some examples of classifying agents by their physiological action are as choking agents, nerve agents, or blood agents. Lastly, agents can be classified by their use as either toxic or incapacitating. Toxic agents can cause death or serious injury. Incapacitating agents cause physiological

or mental effects that can last for hours or days.[Ref. 8: p.4]

2. Factors Determining Effectiveness of Chemical Agents

Some factors that determine how long a chemical agent remains effective are weather, terrain, structures, method of dissipation, and physical properties of the agent. Temperature, wind speed, relative humidity, temperature gradient, and precipitation are the major weather conditions that effect chemical agents. For this simulation all weather factors were determined from historical data for the modeled Monterey area. Because of this, the author will not go into great detail on how weather conditions effect chemical agent's effectiveness. The reader can refer to Reference 9 for a more in depth discussion.

How the chemical agent is disseminated also plays a role in the effectiveness of the agent. Vapors do not last in an area as long as a liquid would. Physical properties such as vapor pressure and volatility determine the rate of evaporation of a chemical. Gases tend to disperse quickly after release presenting a short-term hazard whereas a liquid will most likely have a longer effect.[Ref. 10:p.5] Vegetation, soil, and elevation of the terrain also contribute to the effectiveness of a chemical agent. Because this simulation occurs in an urban area, the terrain

factors do not necessary apply. Urban areas can raise the temperature gradient of a chemical because of the enclosed asphalt and concrete area. Buildings can channel the chemical dispersion by blocking airflow and adjusting wind currents. These are just some the effects that first responders must handle when dealing with a chemical attack within an urban area.

3. How Chemicals enter the Body and Dosage Levels.

There are many ways that a chemical agent can enter the body. Gases can be inhaled by any part of the respiratory tract from either the nose or lungs. The eyes, lungs, skin and especially areas of the skin where sweating is present absorb gases quickly. Wounds present an easy opportunity for a chemical agent to enter the body. Chemicals can be ingested from contaminated food or liquids. The effects of a chemical agent on the body can vary depending upon how the chemical was induced into the body and the amount of exposure.

The dose of a chemical is absorbed into the body is usually expressed in milligrams per kilogram (mg/kg) of body weight. When dealing with a chemical in a gaseous state, the two most common ways of discussing the dosage is the Median Lethal Dosage (LCt_{50}) and the Median Incapacitating Dosage (Ict_{50}). The Median Lethal Dosage (LCt_{50}) is defined as, "the

dosage from a vapor or aerosol that is lethal to 50 percent of exposed, unprotected personnel at some given breathing rate."[Ref. 8:p.9] The Median Incapacitating Dosage (Ict_{50}) is defined as, "the amount of inhaled vapor that is sufficient to disable 50 percent of exposed, unprotected personnel".[Ref. 8:p.9] The unit of measure to express these dosages is mg-min/m^3. This unit of measure is based upon the amount of the chemical in the air for a certain time divided by the area of the exposure. Dosages can be expressed using other measures. LCt_{90} is the dosage of a vapor that would kill 90 percent of exposed, unprotected personnel.

As with every unit of measure there are human factors that affect the manifestation of chemical poisoning symptoms. A person's rate of breathing or what activity the person was doing at the time of the exposure are a few such examples. Because the body has the ability to detoxify over time, the individual's body composition can also vary the actual dose that a person receives. In this study, these variables are not explicitly examined. The dosage values are based upon the amount of the agent a person receives breathing at a rate of 15 liters per minute conducting light activity. Examples of light activity are sitting on a bench outside talking, or doing deskwork. The Chemical toxin, (Ct)

dosage also assumes a 70-kilogram person in a moderate climate with average humidity. [Ref. 8:p.9]

C. TREATMENT

As mentioned above, the body can detoxify certain chemical agents. Unfortunately, most agents have cumulative effects. This means that exposure to a very small concentration of a chemical, can cause death if the person remains in the exposed area for a sufficient period. Another case might be if the exposed person moves to an unexposed area and then receives another non-lethal dosage, the combined effect might be sufficient to kill him. An additional factor that makes treatment of a chemical attack difficult to manage is that the rate at which the chemical symptoms are displayed vary depending upon the chemical used. For example, blister agents can take up to 10-12 days before symptoms appear. [Ref. 8]

Nerve agents as played in this study display symptoms almost immediately. Death can occur within 15 minutes of exposure. To prevent this, antidotes must be administered within minutes of a person receiving the lethal dosage of an agent. Antidotes for a nerve agent are atropine and 2-PAM chloride. 2-PAM re-stimulates the enymze acetylcholinesterase (AchE). AchE prevents the accumulation of acetylcholine after its release in the nervous system.

Acetylcholine is needed for voluntary muscles and nerve endings of the autonomic system and many structures within the central nervous system. Atropine blocks acetylcholine preventing its build-up in the nervous system.[Ref. 8]

D. SARIN

The nerve agent sarin was used for this study. Nerve agents are the most useful to terrorists because only small amounts are needed to cause a substantial number of casualties. Sarin was the chemical used in the Tokyo Subway attack. Sarin (also known as GB, chemical name isopropyl methylphosphanofluoridate) is a colorless and ordorless liquid. G. Shrader discovered it in Germany in 1939. The chemical can be synthesized by a moderately competent organic chemist, with limited laboratory facilities.[Ref. 10] It is estimated the cost per casualty using a nerve agent is approximately $600 dollars. Sarin is most rapidly absorbed through the respiratory system. Absorption through contact with the skin or eyes can still cause problems to the individual, but the absorption is slower except at higher environmental temperatures. Different symptoms of exposure to the chemical result depending on the concentration level. At a low concentration level the symptoms are: headaches, increased salivation, increased nasal secretion, constricting of the pupils, and trouble

breathing. At a high level of concentration the symptoms are: coughing, greater difficulty breathing, increased perspiration, nausea, vomiting, diarrhea, and effects on the muscular system. Death occurs by suffocation due to effects on respiratory musculature and respiratory center in the central nervous system.[Ref. 11]

As a nerve agent, sarin has a very rapid rate of action. Death can occur within 15 minutes of the lethal dosage. The body has an extremely low rate of detoxification for this agent; therefore, sarin's effects are considered cumulative. The LCt_{50} respiratory dosage is 100 mg-min/m^3 resting and 70 mg-min/m^3 being mildly active. The minimum effect of the chemical is shown at 1 mg-min/m^3. Another interesting fact about nerve agents is that clothing exposed to the agents radiates the effects for 30 minutes after contact with the vapor. If exposed to sarin, one should immediately flush the eyes with water and decontaminate clothing using a bleach substance such as typical household bleach. In most cases sarin will dissipate from an exposed area within a couple of days.[Ref. 8]

In summary, forming the initial timeline will establish the time sequencing for our scenario development. We must however be cognizant of sarin's rapid effects on the body. Also, understanding what other factors induce change on the

chemical spread must be taken into account. Having an understanding of how chemicals enter the body and what factors effect the spread of chemicals in mind, we move forward with our simulation development described in the next chapter.

III. MODEL/SIMULATION DEVELOPMENT

A. CONCEPT

The goal in any model is to create a simulation that accurately portrays what is suppose to happen and analyze possible future events. Because many parameters have not been established, or they change frequently during a chemical attack, this task initially appears difficult. Taking a second look at the problem, we realize that if we use established parameters with sound assumptions the problem is quite simple. Also, we can use the information we gain in the Janus simulation to establish undetermined parameters that will help maximize time, personnel, and equipment in the event of a real terrorist chemical emergency. We will use the initial timeline as our baseline for the model. As mentioned earlier, established parameters are from the Pacific Grove, CA exercise and current chemical references defining response times for chemical actions. Assumptions are made based on modeling the "best case" scenario in terms of response times and saving human life. Wanting to maximize the availability of data to be collected, Monterey, California serves as the location for the simulation scenario. The bus station in the heart of the

city serves as the target at one of its busiest times of the day - 1700 hours local time.

B. PARAMETERS

As mentioned above, the timelines for the model were gathered from the Pacific Grove, CA exercise and current chemical references defining response times for chemical actions. Some parameters were determined by the author's own personal measurements. For example, the average time from the initial chemically contaminated area to the nearest hospital is approximately five minutes in one direction. This value was determined by actually timing how long it took to drive the distance. The average mean density population of the area for the model is 1,478 persons/ per square kilometer. This value was derived by using the latest census information and dividing the current population of Monterey by the city's area in square kilometers.[Ref. 12] This value determines the expected number of casualties per a certain amount of sarin as the chemical spreads through the area.

The average density population value is not the most accurate number to use at the chemical release location. This is because a terrorist would most probably want the most populous area available to obtain high casualties. Observing the target area for ten days at a random time

between 1700-1800 hours, the average population at the bus stop was 45 people. This count is also important in determining the initial number of deaths because of sarin's quick dissemination property. The following lists the parameter values used in the model.

- The effects of the chemical are displayed within 10 minutes.
- 60% of the chemical released is disseminated in the air, while 40% remains in liquid form.
- Total assets available within the first four hours of the incident are: 15 fire engines, two HAZMAT vehicles, six ambulances, seven police vehicles, one medivac helicopter, and three buses [Ref. 7].
- Assets will be deployed to the scene in packages called "Strike Teams" which include 16 fire fighters and five fire engines per team.
- Strike teams are composed of the five most ready vehicles closest to the scene.
- 55 firefighters are available within the four-hour period.
- First ambulance, police, and fire vehicles arrive at the scene within 4 minutes.

- The one way travel time from the accident site to Community Hospital of the Monterey Peninsula (CHOMP) is 5 minutes.
- One way travel time from the accident site to Natividad Memorial Hospital (NMH) is 38 minutes.
- One way travel time from the accident site to Salinas Valley Memorial Hospital (SVMH) is 28 minutes.
- One way travel time from the accident site to Watsonville Community Hospital (WCH) by helicopter is 11 minutes [Ref. 7].
- Helicopter turn around time from the hospital to the landing zone is 34 minutes [Ref. 7].
- Helicopter refueling takes 16 minutes [Ref. 7].
- Triage rate is 30 seconds per minor injury, and one minute per major injury [Ref. 7].
- 12 firefighters are needed to man and conduct the decontamination site.
- The decontamination rate is 12 persons per hour, or 3 persons per 15 minutes [Ref. 8].
- Three patients can be loaded in an ambulance in 2 minutes [Ref. 7].

- Three patients can be unloaded from an ambulance in 4 minutes. Of the three patients, only two serious victims can be transported at one time [Ref. 7].
- One minute is needed to restock the ambulance with medical supplies [Ref. 7].
- Dead victims are ignored until all other casualties are moved to the decon site.
- The average population at the bus stop is 45 people at the time of the chemical attack.
- The average mean density population of the area for the model is 1,478 persons/ per square kilometer.
- Ambulances hold 32 gallons of fuel with a consumption rate of one gallon per hour stationary and consume nine gallons per hour while moving.
- Fire trucks hold 60 gallons of fuel with a consumption rate of eight gallons per hour stationary and consume 12.5 gallons per hour while moving.
- Buses hold 90 gallons of fuel with a consumption rate of five gallons per hour stationary and consume 15 gallons per hour while moving.

- Police motorcycles hold eight gallons of fuel with a consumption rate of .1 gallon per hour stationary and consume 2 gallons per hour while moving.
- HAZMAT vehicles hold 42 gallons of fuel with a consumption rate of .2 gallons per hour stationary and consume five gallons per hour while moving.
- The medivac helicopter holds 362 gallons of fuel with a consumption rate of 148 gallons per hour stationary and consumes 148 gallons per hour while moving.

C. ASSUMPTIONS

An assumption is a factor that makes the simulation viable reducing the human factor variability and other unknown sources of error. The following is a list of the assumptions made for this simulation.

- Ambulances travel the posted speed limit.
- All vehicles at h-hour are 100% full with fuel and medical supplies.
- Ambulance routes provide the fastest times from the accident location to the hospitals.
- Police can start initial triage but not perform on-site treatment [Ref. 7].

- Firefighters and ambulance personnel are equally able to perform on-site treatment [Ref. 7].
- Because of breathing apparatus, only firefighters can treat and move casualties until the patients have been decontaminated.
- Enough atropine is available to treat all casualties.
- Additional transportation such as buses are available to carry patients to hospitals if needed.
- The weather will not change after the chemical is released.
- The area will be secured within one hour; hence casualties will be assessed only by the mean population density of the area.
- The HAZMAT team can determine the radius of the chemical precisely.
- Water from the decontamination site is controlled and does not cause any more contamination to the area.
- Victims showing more severe signs of the chemical effects will receive decon first.

- The chemical travels through the air at a rate of 2.79 meters per second. The wind speed for this rate is a constant 5 kilometers per hour.[Ref. 9]
- The decontamination site will be as close as possible to the incident location to expedite the movement of the casualties.
- The first Strike team will arrive within 12 minutes of the activation call.
- The second Strike team will arrive within 30 minutes of the activation call.
- The third Strike team will arrive within 40 minutes of the activation call.
- Firefighting vehicles will be used in the contaminated area to gather casualties more quickly in scenarios with 100 or more casualties.
- Firefighters and their equipment will not be included in the total time of the operation (The exercise is complete once the last casualty arrives at the hospital).
- A second decon site will be established for an incident involving 50 or more casualties.

D. CREATING THE SIMULATION USING JANUS

1. Terrain

The simulation uses digitized terrain from the National Imagery and Mapping Agency (NIMA) to display elevation and vegetation. Because of this, there were not any major problems ensuring accuracy within this spectrum of the simulation. The author did create the coastline and various lakes within the area of operation. Figure 2 gives an overview of the area to be modeled and also highlights the major roads connecting the major hospitals in Salinas to the Monterey Bay area. Appendix A, beginning on page 75 depicts the modeled area after being created in Janus.

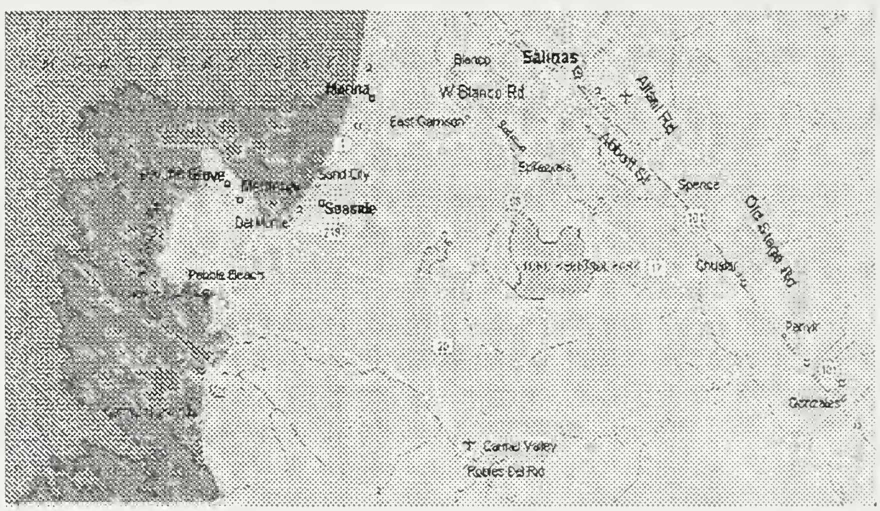

Figure 2. Overview Map of the Modeled Area

"From Ref. [12]"

Developing the road network was the next task to ensure that movement of the simulation entities was accurate. Entering Janus' Terrain Editor allows access to develop roads for the simulation. Two road types were developed for this exercise. The first represents the state Highway 1. The second represents the state and local roads. The major differences between the two roads are in the width and what speed can be obtained on each. Janus not only allows the modeler to determine such characteristics of the road network as width and type of pavement, but also the maximum speed that can be obtained while on that particular road. This aspect is absolutely necessary in helping to identify the times for casualty evacuation. For example an ambulance can exceed speeds over 70 miles per hour, but because of terrain, type of road or other constraints may be able to only to go half its maximum speed.

2. Urban Areas

To create the populated areas one remains in Janus' Terrain Editor. Using a detailed map to determine the general shape and layout of the city is the best tool available. Janus also takes into effect the same movement considerations within the built-up area as it does with roads. This is a very desirable trait since creating roads within the city can be a very tedious task. This allows the

modeler to set established speed limits within the entire city and not draw every street within the city. The icons will move at the same speed within the city as they would on a created road. The modeler can then focus efforts on specific routes within the city to change speed restrictions if so desired. The created routes are shown in Appendix A.

Another useful feature of Janus is the ability to set line-of-sight parameters within the city. This allows the user to adjust visibility within the city. This visibility may be reduced because of buildings blocking the unit's line-of-sight. This parameter depends on the height of surrounding buildings and the number of buildings within a particular area. Adding this feature with Janus' "closed" property provides a realistic scenario where rescue workers must search the contaminated area for casualties. Since we are modeling the best case scenario, this aspect was not investigated in detail in this simulation, but rather mentioned for future study in replicating actual performance or for exercises requiring decision-making by local leaders. One could combine the above-mentioned features with Janus' capability to model the effects on the individual in protective gear. The effects of a decision to conduct a detailed search of an area versus a quick search of the area could be examined. The effects due to individuals being in

protective clothing is discussed in more detail in section four of this chapter.

3. Creating Icons

Creating the individual entities and systems that are used in the exercise is the most prominent role in developing the simulation. The author feels this area is where Janus is truly superior to other simulations. Having the ability to monitor a particular unit or observe the entire operation as it unfolds demonstrates valuable lessons that would be missed in analyzing simple numbers from simulation output.

Creating an entity requires one to establish certain parameters within three different Janus tools. The first simulation tool is called the Symbol Editor. This is where the entity receives its cosmetic appearance. Most Janus systems already have an icon developed within the Symbol Editor, so by modifying some current systems it is fairly easy to create figures such as helicopters and people. Using the mouse-driven drawing commands, other particular icons can be created such as fire engines and ambulances.

The key to modeling each entity accurately lies within the second simulation tool used called Combat Systems Database. Within this data structure, the general characteristics of each entity are developed. The entity's

maximum road speed, fuel consumption while stationary and moving, are examples of the information inputted for each system modeled. Other attributes that can effect the simulation such as height, weight and the capability of a vehicle to transport people can also be represented.

The last simulation tool, Force Definition, serves as an organizing file to store all the created participants for the simulation. This tool has features that make the model easier to develop and more cosmetically pleasing to the eye. The ability to define aggregates for each icon represented makes viewing the exercise easier to follow. For example, in this simulation, one person represents either 11 or 22 people. The large number of participants, each represented by a single icon would clutter the view and hide more interesting aspects of the simulation. This aggregation appears to have no harmful effects. Also through Force Definition, the model can easily add or delete units to compare different scenarios and investigate the significance of those differences. [Ref. 14]

4. Miscellaneous Modeling Features in Janus

After the above mentioned simulation tools are used for scenario development, the final parameters of the model are inputted in the Janus Workstation Display. This screen is the initial screen shown before the exercise begins. From

this screen the modeler can deploy the icons to their initial positions within the city. Icons can also be put into chemical protection representing breathing apparatus and protective clothing. The effect of this status is to make the entities move slower and detect individuals with less accuracy. [Ref. 6:p.51]

Developing the initial routes for the icons is also made during this phase of the model. Figure 3 shows how these routes are created within the simulation. The timed

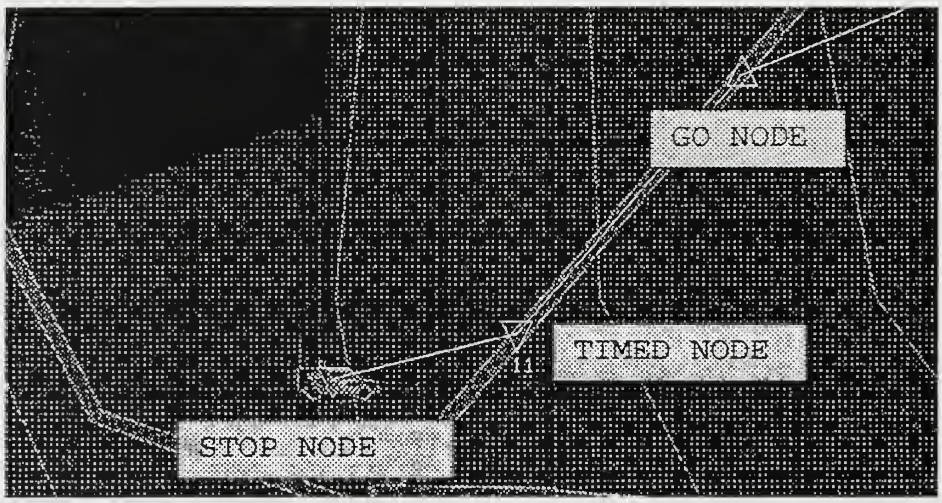

Figure 3. How an Entity Moves on a Route "After Ref. [5]"

node allows the icon to stop at a certain point along the route until the pre-determined time has elapsed. Using this type of node, ambulance routes were developed from the accident site to the various hospitals. This feature helps in reducing variance inputted into the model. For example,

the modeler may start a vehicle at one time during one scenario, but forget to start the vehicle at the same time in the next run of the simulation. This can result in inaccurate data results. Using the time nodes, the modeler will not have to worry about keeping track of when to start and stop a vehicle, therefore variance from human error is reduced.

Line-of-Sight (LOS) can also be measured for each entity. This feature enhances the model's realism. Figure 4 depicts the LOS viewing fan of an entity. The modeler can change the orientation and the width of the fan. Terrain and buildings are taken into account by Janus' algorithm for line-of-sight. For example, the broken line in figure 4 shows where the unit's line-of-sight is obscured by terrain or an urban feature.

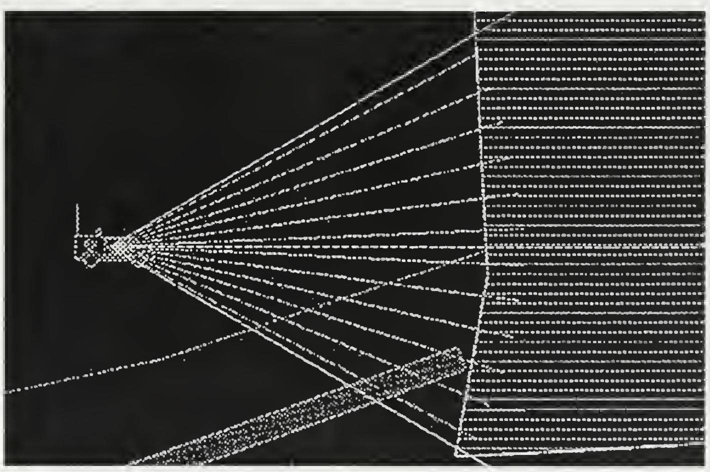

Figure 4. Entity's Line-of-Sight "After Ref. [5]"

The final point discussed within this section is the capability of the Janus model to view areas of interest in the simulation that are not captured explicitly within the terrain file. The Command and Control (CAC) menu allows the modeler to add specific graphics to the main simulation screen. This function is how the various chemical dispersion patterns, hospital sites, and decon site are exhibited in the model. The graphics are drawn using the mouse-driven commands. In this manner the overlay of the chemical dispersion from the HPAC model was displayed on the viewer's screen.

E. MODELED SCENARIOS

Investigating the chemical attack size the modeled area could effectively handle, using the aforementioned parameters and assumptions, was one of the major interests in this thesis. To develop a sensitivity analysis, three different scenarios were created. The first scenario was designed to establish a lower bound on the number of casualties the system could properly manage within the first four hours of the attack. In this scenario, 22 casualties all receive a non-lethal dosage of sarin. The victims need to be decontaminated, and then evacuated to a hospital. The intent of this plan was to develop and validate the

parameters and assumptions of the model without over stressing the resources available.

The next scenario was designed to stress the available resources, and make full use of additional assets. One hundred casualties receiving a chemical dosage between 8,000 $mg\text{-}min/m^3$ to 1 $mg\text{-}min/m^3$, provided the stimulus. Because the closest hospital to the site of the incident has limited laboratory resources, respiratory equipment, and physicians a patient rotation was developed. A patient rotation is how emergency decision-makers decide the number of victims that can be transported to the various hospitals within the area that will provide support for the accident. The goal of the rotation is to not deplete any of the supporting hospital's resources over the time required to treat all the victims. Our modeled rotation corresponds to the actual rotation that emergency responders would try to establish for an actual crisis involving this number of victims. The modeled rotation is two severe and three minor patients between Community Hospital of Monterey Peninsula (CHOMP), Salinas Valley Memorial (SVMH), and Natividad Memorial (NMH) Hospitals. Severe is defined as a patient not being stable after the antidote has been administered. Minor is a stable victim, but one who has been exposed to enough of the chemical to display symptoms. Once the severe victims

are evacuated, five minor patients can go in the rotation. The emergency helicopter is used in this exercise to assist the transportation of victims. The intent of the second scenario was to present a situation where resources outside the county would have to assist in the attack response because available resources would be exhausted by the large amount of victims.

The last scenario follows the scenario mentioned above in concept, but the intent is to find the number of casualties the system could withstand within the initial four-hour period. This of course will be less than the number of victims from scenario two. The total number of assets used in the previous scenarios remain the same. Casualties receive a chemical dosage between 8,000 mg-min/m^3 to 1 mg-min/m^3, the same as scenario two, but the exposed area is reduced. By reducing the chemically exposed area we expose fewer people. This has the same effect as a terrorist releasing a smaller dosage of the chemical. The hospital rotation remains the same as scenario two, and the emergency helicopter still flies critical victims to hospitals outside the county.

In summary, we have inputted all the parameters and made sufficient assumptions to allow us to create our model. When we run our simulation we can validate the model by

checking the simulation data against our established parameters from References 6 and 7. The three scenarios developed also helped validate our model by providing a wide range of data. We are now ready to collect the data and answer the questions we set out to answer at the beginning of this thesis which helps determine how local communities can better prepare for and handle a chemical terrorist attack.

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IV. DATA ANALYSIS/ RESULTS

A. GRAPHICAL AND STATISTICAL ANALYSIS OF THE DATA

Before discussing the measures of effectiveness (MOEs) used in this simulation, a graphical and statistical analysis was conducted to see if the model's output followed an identifiable type of probability distribution. Having conducted a reconnaissance from the incident site to the various hospitals, we compare our simulation times with the times measured for travel to the different hospitals. Wanting to acquire a wide range of simulation data points for this parameter, we make our sample size as large as possible. The author conducted ten simulation runs for each scenario. Summing the number of hospital trips from all scenarios gives us a large random sample size to analyze. For example, the sample size for the number of hospital trips to CHOMP for three scenarios was a total of 239 trips. From this data we can determine simple probability values such as the mean and variance of travel times to each hospital. With these probability values available, we can then explore our data graphically and numerically as described by the following analysis. It should be noted that analyzing numbers from the simulation is not the major point of emphasis within this thesis. The most substantial work

of this thesis was to develop an accurate model that local agencies can use to prepare for a terrorist chemical attack. Once the model is complete, examining the differences within the simulation output is just one of the future areas of work that could be studied in more depth.

Table 2 shows the summary of statistics for all four hospitals used in the model.

Hospital	Type of Movement	Measured Time (Sec)	Mean Time From Model Runs (Sec)	Variance $(Sec)^2$	Standard Deviation (Sec)	Number Of Samples
CHOMP	Amb	300	284.85	26.43	5.14	239
SVMH	Amb	1680	1619.49	1366.76	36.97	130
NMH	Amb	2280	2212.65	1124.96	33.54	60
WCH	Helo	660	698.19	85.36	9.24	108

Table 2. Summary of Statistics for the Simulation

Because of the large sample sizes for each event, we should expect the data to capture the nature of their underlying distributions. Figures 5,6,7, and 8 graphically display the results of each event. Each figure consists of four graphs of the data for movement to each hospital. The first graph; a histogram, gives a view of the distribution shape. The second graph is a boxplot that gives a clear representation

of the median (the solid white line inside the box), and the upper and lower quartiles (the lower and upper ends of the box). Each point from the data, which occurs outside 1.5 times the interquartile range, is displayed as an outlier by a single black horizontal line. The third graph is a density plot, which is another version of the boxplot except smoother. The density plot shows the probability that a certain value within a particular interval is the area under the curve. For illustration, one can think of the density curves within this thesis as representing the distribution of time. For example, the probability that the time will be less than 300 seconds in figure 5 is the area under the curve to the left of 300. The fourth graph on each page is the quantile-quantile (qq) plot. The qq plot consists of a plot of the ordered values of the data against the quantiles of a "standard" normal distribution with mean zero and variance one.[Ref. 15: p.45]. One of the uses of the qq plot is to compare an empirical distribution with a theoretical distribution. In our case, we compare our data against the normal distribution. If our data is similar to the normal distribution the points from the data will closely lie along the diagonal line which represents the normal distribution. If the normal distribution does not fit our data the points

will vary in magnitude from the straight line. [Ref. 17:p.13-17)

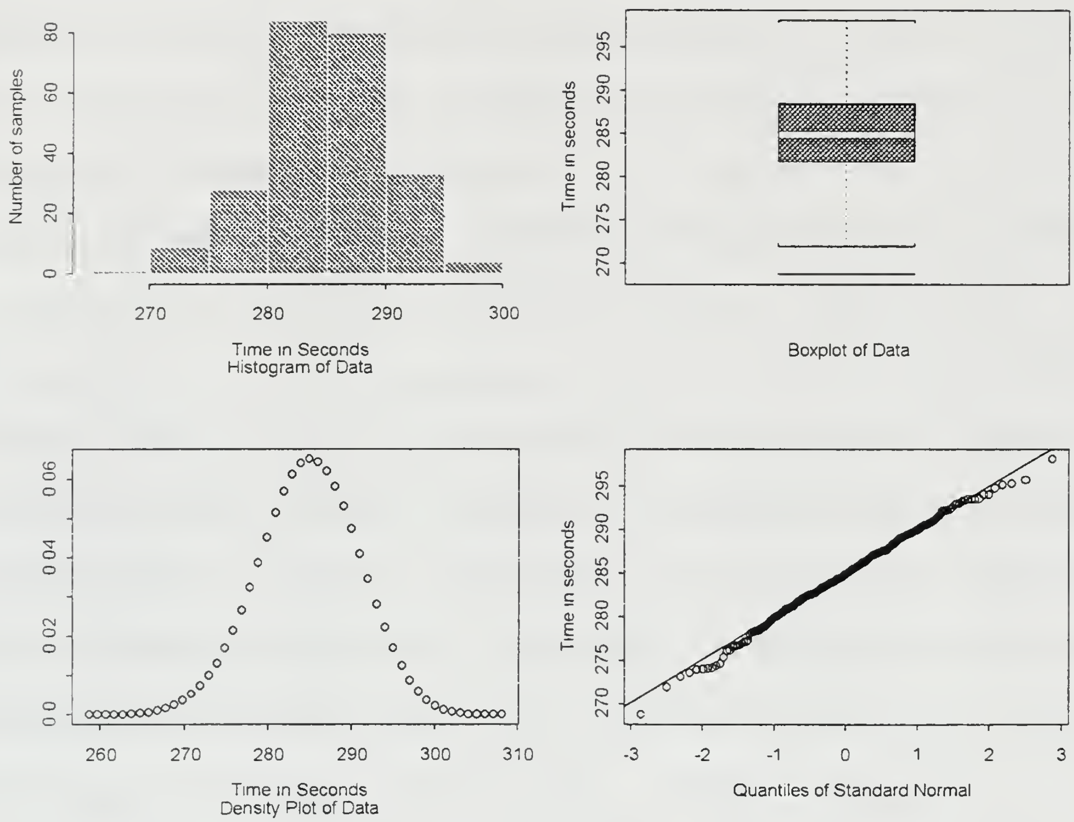

Figure 5. Graphs of CHOMP Data "After Ref. [15]"

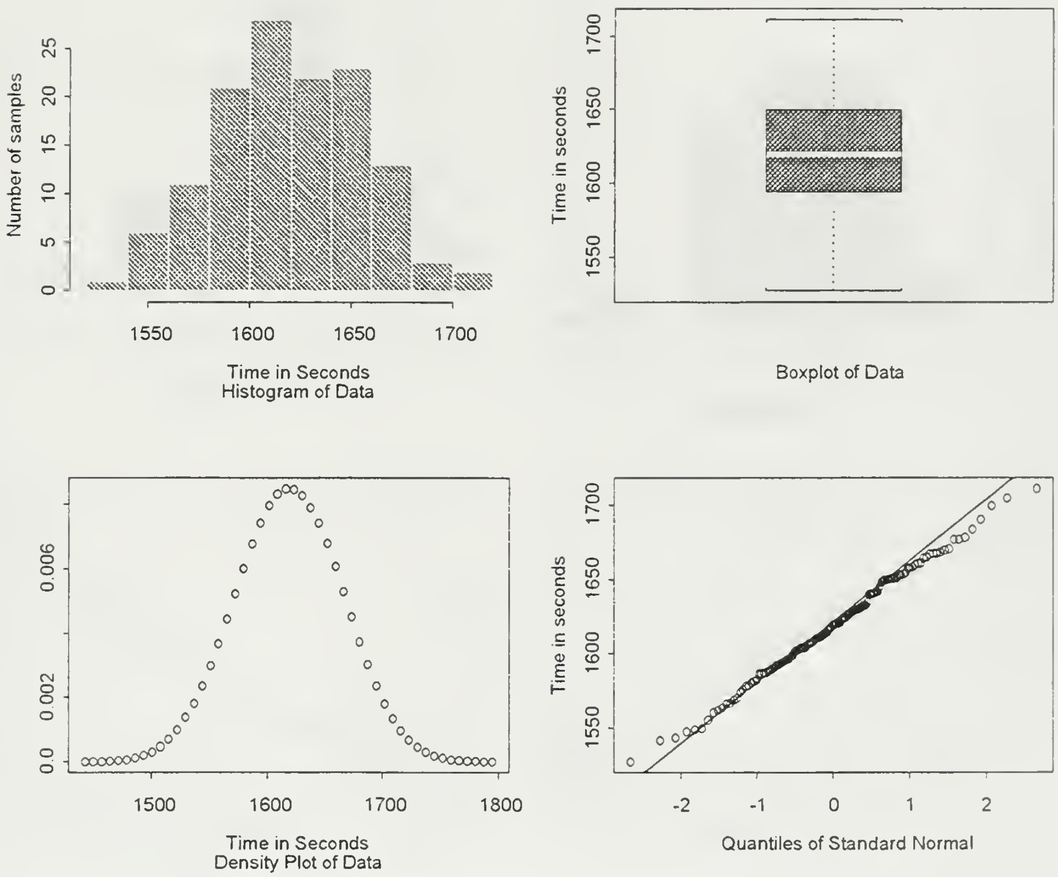

Figure 6. Graphs of SVMH Data "After Ref. [15]"

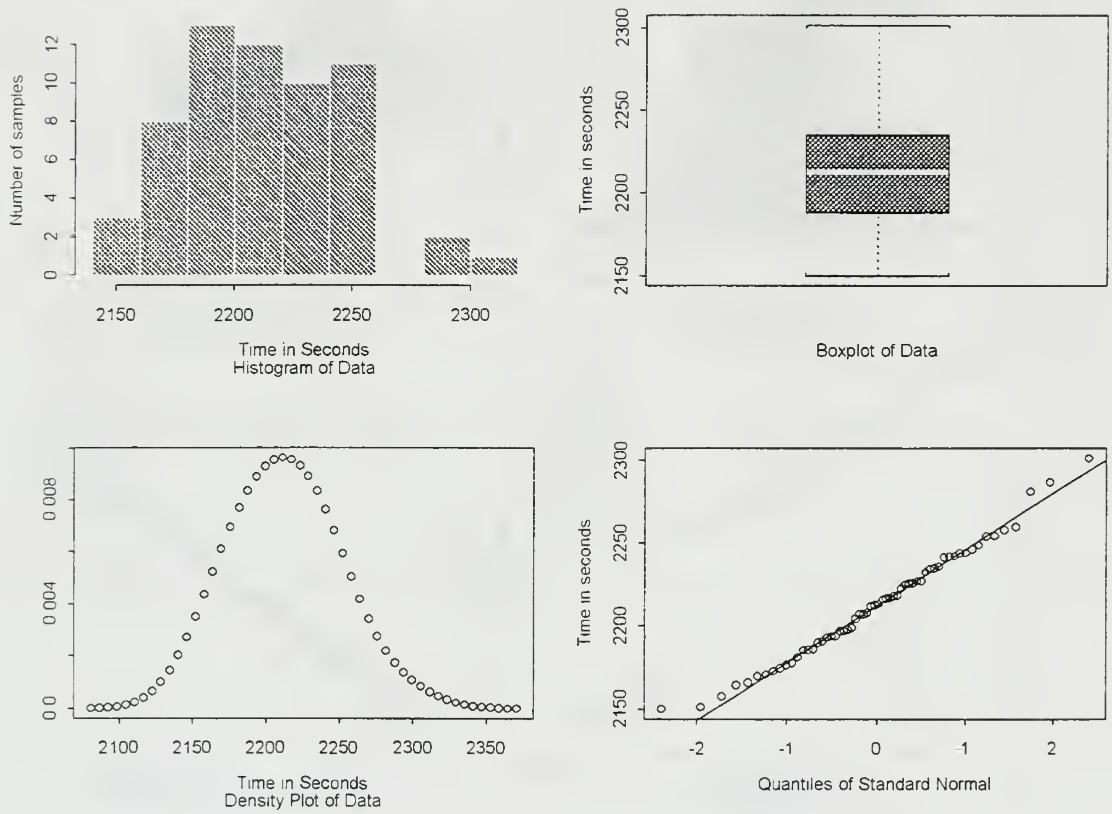

Figure 7. Graphs of NHM Data "After Ref. [15]"

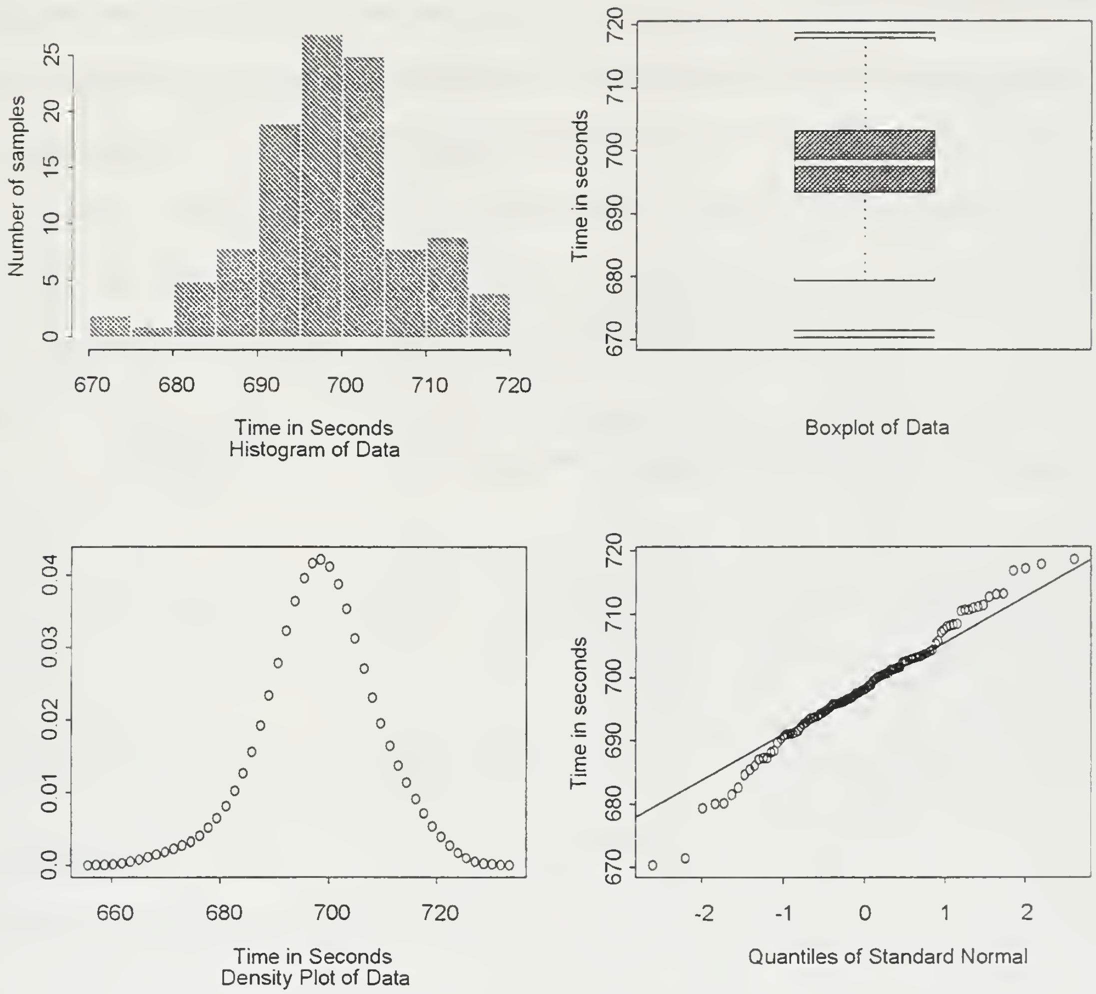

Figure 8. Graphs of Helicopter Data "After Ref. [15]"

Reviewing the graphs for each event we see each set of data appears to follow the normal distribution as expected. The density plots and the quantile-quantile plots for each data set clearly shows this assumption. We do see some variance in the qq plots at the tails of each data set and the straight line representing the normal distribution. This is expected, because most data sets fit more accurately in the middle of the data sets than at the endpoints. This can be explained by the sample size of the data set as seen in figure 8. The smaller the sample size, the more samples are required before the Central Limit Theorem (CLT) takes effect. The CLT states, "that as the sample size (n) increases the sampling distribution of the mean becomes approximately normal, regardless of the variable's frequency distribution. The sampling distribution will be centered around the variable's population mean μ, and the sample's standard deviation approaches $\sigma/(n)^{1/2}$, the variable's population standard deviation divided by the square root of the sample size." [Ref. 17:p.27]. Because of this fact, we need another way to conclude our data resembles the normal distribution. This is accomplished by the Chi-squared Goodness of Fit test. Each sample was compared to the normal distribution with the mean and standard deviation taken from each sample. The test provides a p-value. This value

represents the probability that if the null hypothesis were true that the test statistic would take a value as extreme or more extreme than what is observed. The null hypothesis we test is that the normal distribution fits the data versus the alternate hypothesis that the standard distribution does not model the data. Equation 1 shows the equation used for computing the chi-squared statistic.

$$\chi^2 = \sum_{i=1}^{k} \frac{(observed_i - \exp ected_i)^2}{\exp ected_i}$$

Equation 1. Chi-squared goodness-of-fit test

The chi-square statistic is determined by grouping the number of observations into k groups. The observed counts in each group are then compared to the expected counts from the hypothesized distribution. In our case under the null hypothesis that the sample comes from the normal distribution, it has a χ^2 distribution with k-1 degrees of freedom. For a predetermined significance level α (we will use $\alpha = .05$), we reject the null hypothesis if our p-value is less than α. The results of the test are presented in Table 3. Because our p-value is higher than any significant

level, we cannot reject the null hypothesis. Therefore, we assume that the normal distribution fits our data.

SAMPLE	χ^2 STATISTIC	DEGREES OF FREEDOM	P-VALUE
CHOMP	8.10	15	0.9195
NMH	1.97	8	0.9820
SVMH	5.46	12	0.9408
HELICOPTER	10.22	11	0.5105

Table 3. Results of Chi-Squared Goodness of Fit Test for Testing Samples Against the Normal Distribution

Realizing that in each ground transportation sample the mean time is faster than the author's measured time, some may question the measured time's accuracy. This perhaps can be explained as we are modeling the "best case scenario", so human intangibles are not modeled. We are not modeling the effects of traffic or having to slow down at intersections. Also, we cannot model the variance that different drivers and vehicles would have on the mean time to each hospital. The helicopter sample is different than the parameter time defined in Reference 7 because actual flight routes and speeds were not known for the simulation.

B. CONFIDENCE INTERVALS

Confidence intervals were determined to find an interval within which we are confident the true value of each sample's mean lies with some degree of confidence. Table 4 displays the 99% and 95% upper and lower confidence limits for each sample's mean.

SAMPLE	MEAN	99% Upper CONFIDENCE LIMIT	99% LOWER CONFIDENCE LIMIT	95% UPPER CONFIDENCE LIMIT	95% LOWER CONFIDENCE LIMIT
CHOMP	284.85	285.71	283.99	285.50	284.20
SVMH	1619.11	1627.48	1610.75	1625.47	1612.76
NMH	2212.65	2223.82	2201.48	2221.14	2204.16
HELO	698.19	700.48	695.90	699.93	696.45

Table 4. 99% and 95% Confidence Intervals in Seconds for all Samples

The differences between the two confidence intervals brings out one of the major advantages of simulation, the cost of gathering data to achieve a certain level of accuracy within the sample estimates. Collecting data requires resources such as man-hours and money to be expended. To gain an idea of how much data needs to be conducted, analysts would like to compute a sample size sufficient to guarantee a certain level of statistical significance. Using the following formula we can determine the sample size.

$$n = \left(\frac{2z_{\alpha/2}\sigma}{L} \right)^2$$

Equation 2. Determining required Sample Size

L represents a predetermined length (our case L = time in seconds), required to ensure the error in estimating the mean is less than a specified amount the analysts is willing to accept.

This statistical concept brings out two major advantages in using the concept of simulation to gather data. The first is it gives the modeler a cheaper solution to collecting the data besides having to spend enormous amounts of time and funds to conduct the true experiment. For example, Table 5 gives the required sample sizes for the four transportation samples.

SAMPLE	SAMPLE SIZE FOR 99% C.I.	SAMPLE SIZE FOR 95% C.I.
CHOMP	29	17
SVMH	364	211
NMH	300	173
HELO	91	53

Table 5. Required Sample Size for Required Confidence Interval

The sample sizes for SVMH, and NMH have a length L, of 10 seconds. Because Equation 2 is calculated using each

sample's standard deviation, CHOMP and the HELO sample have an L of 5 seconds. Table 5 shows the vast difference in the confidence intervals' sample size. The smaller the desired length L, the larger the sample size must be. This means more resources spent to acquire the desired result. Another point of interest is looking at the confidence intervals in Table 4 one will see that the answer to which confidence interval to use is a difficult question to answer. Is it better to use a smaller sample size, or use more resources to gather a larger sample size that has more accuracy? This question is difficult to answer because the higher the desired degree of confidence, the longer the interval. If one thinks of the interval in terms of precision, a dependable interval may be inaccurate if the endpoints are far apart. The gain in having a larger interval means a loss in accuracy. [Ref. 16: p.281] The second major advantage of using the simulation concept is it gives a modeler a better feel for data obtained from an experiment. In most cases experimentation is only one valid trial at a time. Simulation can provide more information in less time because more simulations can be conducted within a certain time. The attentive data collector can then more clearly see patterns developing in the data that may go undiscovered if not for the repetition of conducting the simulation.

C. MEASURES OF EFFECTIVENESS(MOE)

1. MOE 1 (Rate of people treated/ time of the entire process)

MOE 1 was developed to determine the rate at which a person is treated for the entire evacuation process. The rate at which people are treated is very important to study for many reasons. The first reason is budget constraints. Communities have limited transportation assets and can only have a certain number of first responders able to react immediately to an incident because of budget limitations. Also, hospitals can only treat a limited number of victims within a certain time before their resources are consumed. By examining our data we can establish the treatment rate for our scenario. The modeler can then study the effects if more ambulances are used or other hospitals are used in the scenario. We can also see the effects if fewer assets are available. For example, two ambulances have maintenance problems and are unable to participate in the exercise. Studying the data, we find MOE 1 depends on three times: the time required to collect and initially treat victims, the time required to decon victims, and finally the times needed to transport victims to the various hospitals. Table 6 displays the MOE value for the three scenarios.

SCENARIO	MOE 1 PEOPLE/ MIN	# OF AMBS EVACS	# OF BUS EVACS	# OF HELO EVACS	AVG TIME (MIN)	# OF PEOPLE TREATED
1	.1131	8	0	0	195	22
2	.2588	11	2	2	255	66
3	.2932	17	3	4	341	100

Table 6. Critical values for MOE 1

Analyzing MOE 1, two interesting results are discovered. The first point of interest is that the maximum number of victims that can be managed within the initial four-hour period is approximately 66. Using the same resources for all three scenarios we find that it would take approximately 341 minutes (5 hours and 41 minutes) to treat 100 casualties. The second point of interest is within the MOE rate of the three scenarios. One would expect the second and third scenario to have a higher rate than the first because of the extra decon site established in scenarios two and three. The difference between scenario two and three lies within the number of bus evacuations. What the extra bus evacuation means to the simulation is that, if the decon site can afford to have victims wait to be transported to hospitals in groups, it is faster than moving victims by ambulance. In other words, there is no time lost by making victims who are able to wait to travel in a group of 12 or 15 rather than not waiting and moving by threes in ambulances. The actual difference between the two scenarios

is 2 persons per hour in favor of the extra bus transportation. We know the model accurately models the distances to the different hospitals as mentioned earlier in this chapter. We also have determined the MOE increases by transporting more victims together than in groups of three as displayed in the difference in MOE 1 between scenarios 2 and 3. From examining these conclusions we determine that, if we really want to increase our rate for MOE 1, we must have the assets available to establish at least two decon sites. Hence, the increase in MOE 1 between scenario 1 and 2.

2. MOE 2 (Number of victims that die/ Total number of people evacuated)

This MOE is important because we would like to know what could be done to minimize the number of deaths. As discussed in earlier chapters, the chemical will have dissipated within the first four hours of the attack, so any advantage the first responders can gain to save time will in turn save lives. The second MOE parallels the first, but is more subjective. The reason for this subjectivity is due to the manner in which the body reacts to chemicals as discussed in Chapter II. We also analyze the HPAC graphs and use the predicted victims for various concentration levels of the chemical to make our estimate. Table 7 depicts the critical data for the MOE.

SCENARIO	# VICTIMS EVACUATED	# VICTIMS DIE INITALLY	# VICTIMS DIE BEFORE DECON	MOE 2
1	22	0	1	.0455
2	66	2	1	.0455
3	100	4	3	.07

Table 7. Critical Data for MOE 2

The column-titled "number of victims that die initially" refers to victims exposed to the initial burst of the chemical and die within the first 15 minutes of the exposure. Even though the numbers may vary based on the discussion from Chapter II, this MOE brings out four points of interest. The first deals with the first emergency responders that respond to the accident. If these units have the equipment and training to identify and treat victims within the first minutes of the incident, lives will be saved. The second is the importance of having atropine available as soon as possible. If the drug was carried in small amounts by firefighters, the five victims that died within the total three scenarios before being deconed may have survived. The third is the importance of the HAZMAT team being able to determine the contaminated area and what type of chemical was released as quickly as possible. This will help focus the limited resources that are available within the first hour of the attack.

Lastly, one might wonder why the value for MOE 2 is the same for the first and second scenarios. The reason is because the author assumed a linear relationship between response packages. Recall from Chapter III that for an incident involving 50 or more casualties, two decon sites were established, while an incident involving less than 50 victims only one decon site was established. Because of the additional decon site the rate the model is able to handle casualties increases with the increase in victims. We see degradation in the rate from the lack of resources in scenario three. Notice that in scenario three the rate of death per total number of people evacuated is almost double the value for scenarios one and two. This shows the stress put on the system by the large number of victims and no change in the resources available.

3. MOE 3 (Average amount of time required to evacuate a casualty to the decon site)

The final MOE is significant because it analyzes one of the critical times from our study of the first MOE. Dividing the critical times into smaller intervals may lead to more important findings. The third MOE combines the parameters from Chapter III with what we found from the simulation. MOE 3 is a combination of the response times to treat a victim and the time required for the casualties to walk in a group to the decon site. If a victim cannot walk,

four firefighters are required to move the victim by stretcher to the decon site. Figure 9 depicts the number of firefighters able to assist in the collection and treatment of the victims over time. Recall from Chapter III that the firefighters will arrive at the scene of the attack in "strike teams" consisting of 16 men and 5 fire engines. Also, a maximum of three strike teams will be able to participate within the first four hours of the incident. The graph only shows firefighters that can aid in the collection of victims. The 12 members needed to establish each decon site are not included. The x-axis is in minutes after H-hour.

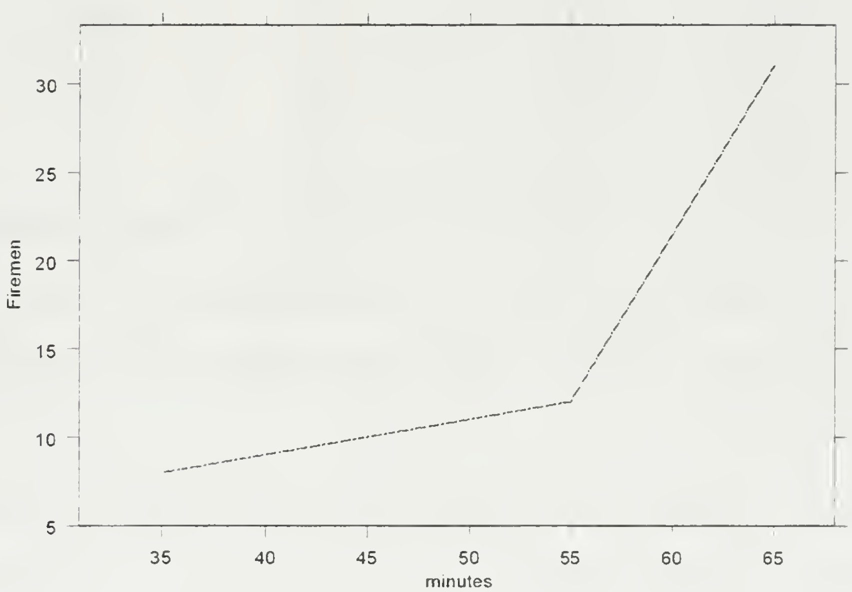

Figure 9. Firefighters Available to Collect and Treat Victims Versus Time

Because we have modeled the "best case scenario" the times are less than expected. Also, the times would be increased if we would have incorporated Janus' "closed system" and the firefighters would have to conduct a vigorous search for victims before treatment is available. Table 8 displays the data collected for MOE 3. Table 8 shows the number of victims collected and initially treated per each group movement to the decon site. For example, in the first scenario all victims were moved in one group to the decon site. In the second scenario, it took the available firefighters three collections to move all 66 victims to the decon site. The third scenario took five collections to move all 100 victims to the decon site. The reason for the increase in the number of movements is based on three obvious factors:

- The number of victims increases in each scenario.
- The difference in the category of the victim (serious or minor) and the number of each category of victim.
- The number of firefighters available at various times in the model.

SCENARIO	VICTIMS MOVED	TOTAL MOVED WITHIN SCENARIO	TIME TAKEN	FIREMEN AVAIL/ USED	MOE 3 (victims/min)
1	1 serious 21 minor	22	18 min	8/8	1.22
2	1 serious 20 minor	21	18 min	8/8	1.17
2	16 minor	37	20 min	8/8	.800
2	19 minor	66	15 min	12/12	1.27
3	1 serious 20 minor	21	18 min	8/6	1.17
3	1 serious 12 minor	34	21 min	8/7	.619
3	1 serious 21 minor	56	21 min	12/12	1.05
3	22 minor	78	18 min	31/31	1.22
3	22 minor	100	13 min	31/31	1.62

Table 8. Collected Data for MOE 3

The average time it took to transport a seriously injured victim by litter or for a group of minor injured victims to walk to the decon site was 12 minutes. Summing all the calculated data for MOE 3, we produced an average MOE value for the entire simulation of 1.13 victims per minute. Analyzing the averaged MOE, the averaged value makes sense. As expected the rate increases, as more firefighters are able to assist. Also, the rate is severely hindered by the movement of one serious victim because it takes four firefighters to move one seriously injured casualty by litter as mentioned in Chapter three. Also, we must remember that one firefighter must stay with one critically injured

victim during the entire evacuation procedure. This is why in the column tilted 'Firemen Available/Used" not all firemen appear to assist in the evacuation, because they are assisting a critical patient. Lastly, we notice the major constraint on this MOE is the foot speed of the victims themselves. For example the fourth entry in Table 8 has 12 firefighters available for 19 minor casualties, but because of collection and the walking speed of the victims it takes the group 15 minutes to reach the decon site.

Analyzing the data, we can make some very important observations. The first is that our data displayed the characteristics of the normal probability distribution, as we expected prior to the simulation. This helps validate the time from the site of the chemical attack to the various hospitals. The second observation is that we have explored three MOEs that answered the proposed questions we had before we started the modeling process. Table 9 captures the three MOEs for the three scenarios. From Table 9, we get a quantification of adding assets to the model. The numerical MOE values are not what we should focus our analysis on, these values will change depending on human factors or assumptions that our simulation can not model. Our focus should be on where does our resourced response to the incident improve. For example, we saw the rate at which

victims die versus total number of victims evacuated decrease by approximately a factor of two when the second decon site was added to the simulation.

SCENARIO / Total number of victims	MOE 1. Rate of people treated/Time of the entire process (People/Min)	MOE 2. Number of victims that die/Total number of people evacuated	MOE 3. Average amount of time required to evacuate a casualty to the decon site (Victims/Min)
1 / 22	.1131	.0455	1.22
2 / 66	.2588	.0455	1.08
3 / 100	.2932	.07	1.14

Table 9. Summary of Calculated MOE Values

In summary, we have shown that we can use our data and model to see where additional assets could improve the evacuation process. This analysis has led to some very important recommendations that are addressed in the next chapter.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The objective of this thesis was to develop a high-resolution model that could effectively aid local governments in crisis management. This objective was met by accomplishing two tasks. We created a simulation that has newly established local response entities like ambulances, fire apparatus and HAZMAT teams that can be used for future simulations. We also have created a terrain file that replicates the Monterey Peninsula and the surrounding area. Both of these major accomplishments now make modeling civilian and military operations within the area encompassing the Monterey Peninsula more accurate and user friendly. Secondly, we accomplished our objective by utilizing Janus to develop three simulation scenarios, using established parameters from previously executed crisis exercises. These scenarios were used to conduct a sensitivity analysis on the maximum number of victims that the local agency's resources could manage. The three scenarios consisted of 22, 66, 100 victims respectively. We also detected and analyzed the times it took to move victims from the chemical site to various hospitals. Lastly, we

discovered a rate it took to move casualties to the decon site under chemical conditions.

The major concern of this study was development of the model, and then to find the upper limit on the number of victims the system could effectively treat within the first four hours of the chemical attack. We found this upper bound to be approximately 66 victims. The major constraints in the various scenarios were the time it took to decon the personnel, and the number of available firefighters to collect and assist the chemically contaminated victims. Finally, the model appears to replicate the parameters and assumptions from Reference 7. We cannot be totally sure we have 100% accuracy within the model since the exercise in Reference 7 did not include chemical play. One must remember that a model is just that; a model, and a change in the parameters will change the model's results.[Ref. 18]

B. RECOMMENDATIONS

This high-resolution model has enormous potential to significantly contribute to the training and study of terrorist chemical attacks in urban areas. Awareness and training within the general public is the best recommendation one can possibly give on this subject. If citizens believe that it will never happen, when it does it will be too late. Sadly, this recommendation will never be

satisfied to the extent that it needs to be. The most important contribution the model could make is to provide an inexpensive tool for first responders to practice their decision-making skills. Using the model to develop actual scenarios to train community response agencies on, or before an exercise is executed would develop valuable experience. The author learned from conducting the simulation how important the communication structure must be within the local response network. This can also be readily shown in the model. Having individuals from different organizations participate in a simulation exercise force each organization to ensure the other members of the crisis action team understand that the decisions they make, or do not make, will effect the entire crisis management plan. Decisions like ambulance management and rotation of patients to various hospitals are easily integrated within the model. Learning how much and which type of equipment saves more lives is just another aspect that could result from model use.

From the scenarios used for this study, we provide several specific recommendations for local agency preparedness. Because of the quick absorption of nerve chemicals it would be wise for firefighters to carry a small amount of the antidote with them while collecting victims.

This will hopefully stabilize more severe victims until they can be transported to the decon site. Having equipment on-hand that will allow for the quickest determination of the radius of the chemical spread and what type of chemical was released also will expedite the process. Giving policemen and emergency medical technicians some sort of protective equipment will not only accelerate casualty processing, but also protect these people since they will most likely at first be responding to a murky situation. Setting up as many decon sites, as possible will also quicken the operation since decontamination is a time consuming process.

From the data, we also learned that it was not necessarily waiting for transportation that was a major concern for non-critical victims. It was the number of firefighters available to set-up and man the decon site, and also collect and move casualties. Having more firefighters available would help this problem, or as mentioned above, more people with breathing apparatus. Lastly, a logical recommendation, but one that is outside the study of this thesis is having more physicians and equipment available at the hospitals would also reduce the overall time of the operation.

In closing, unfortunately many of the recommendations mentioned cost money. Using this model gives the community a

cost-effective method to develop and study this type of event. The savings in training cost that the model provides could allow much needed equipment and personnel to be added to the community's resources. A major use of the model would be to continue to mature vital decision-making skills. These decision-making skills will save human life in the event of a terrorist chemical attack.

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APPENDIX A. SCENARIO IMAGES

Selected images from the simulation appear in this appendix. The figures are grouped into four categories. The four groups are: General, Scenario 1, Scenario 2, and Scenario 3. A brief explanation of each picture is listed beside the figure number.

<u>General</u>

<u>Scenario 1</u>

Scenario 2

Scenario 3

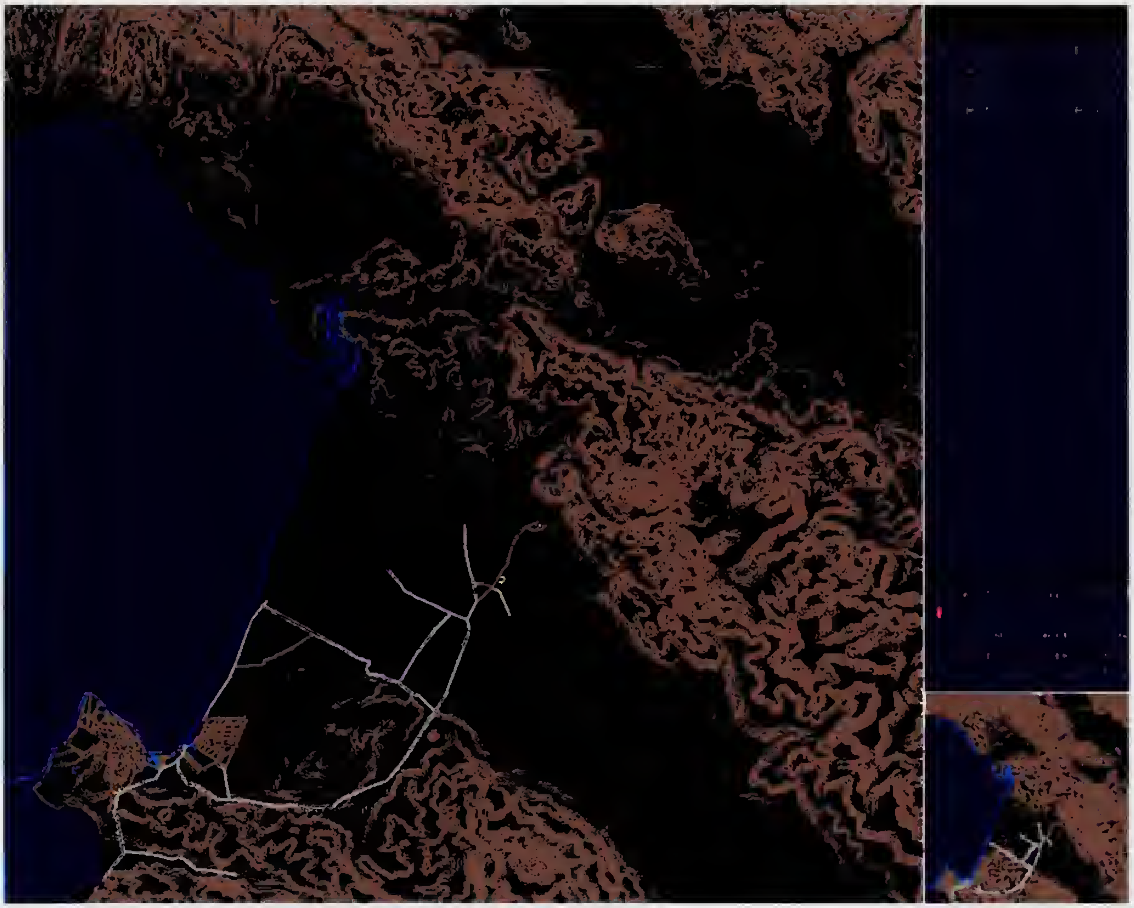

Figure A1. Overview of Modeled Area

Figure A2. Enlarged View of the Modeled Area

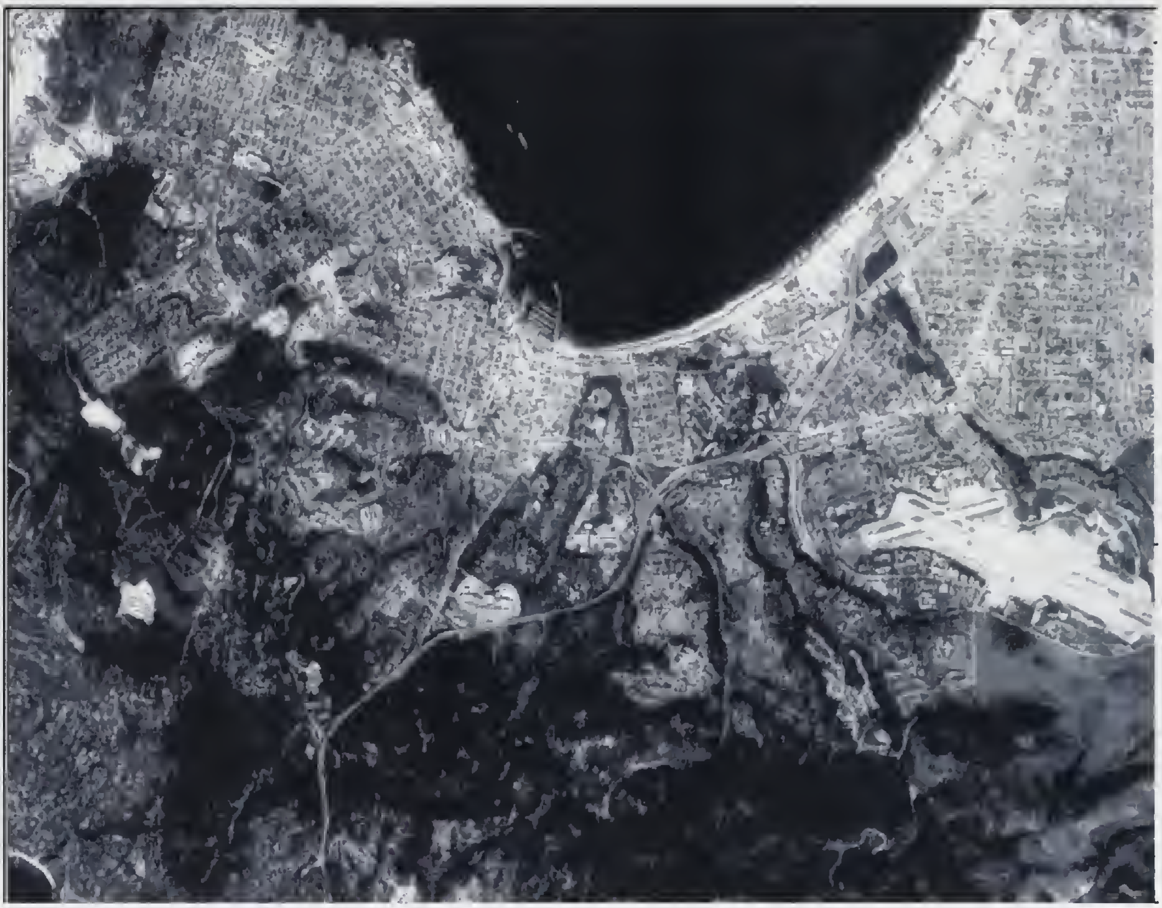

Figure A3. Satellite View of the Modeled Area

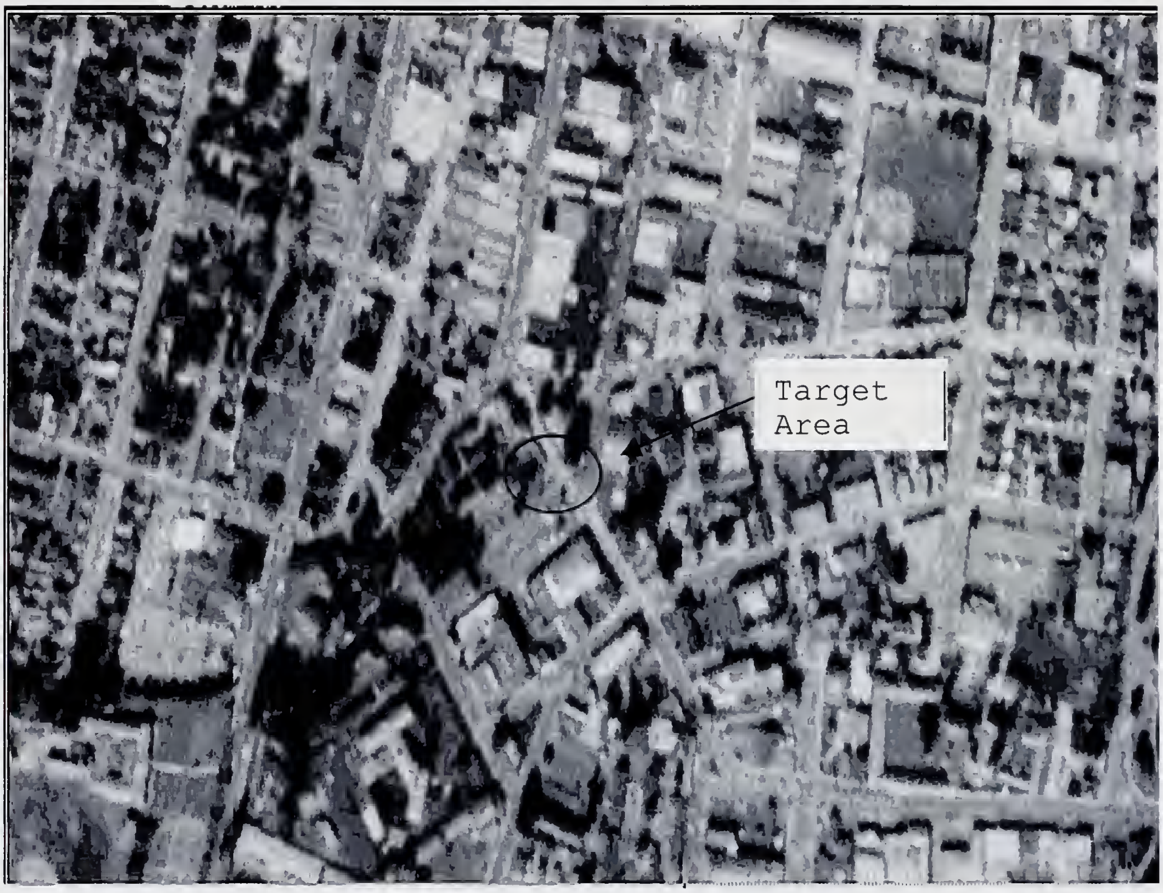

Figure A4. Enlarged Satellite View of the Target Area

Figure A5. Pictures of Target Area

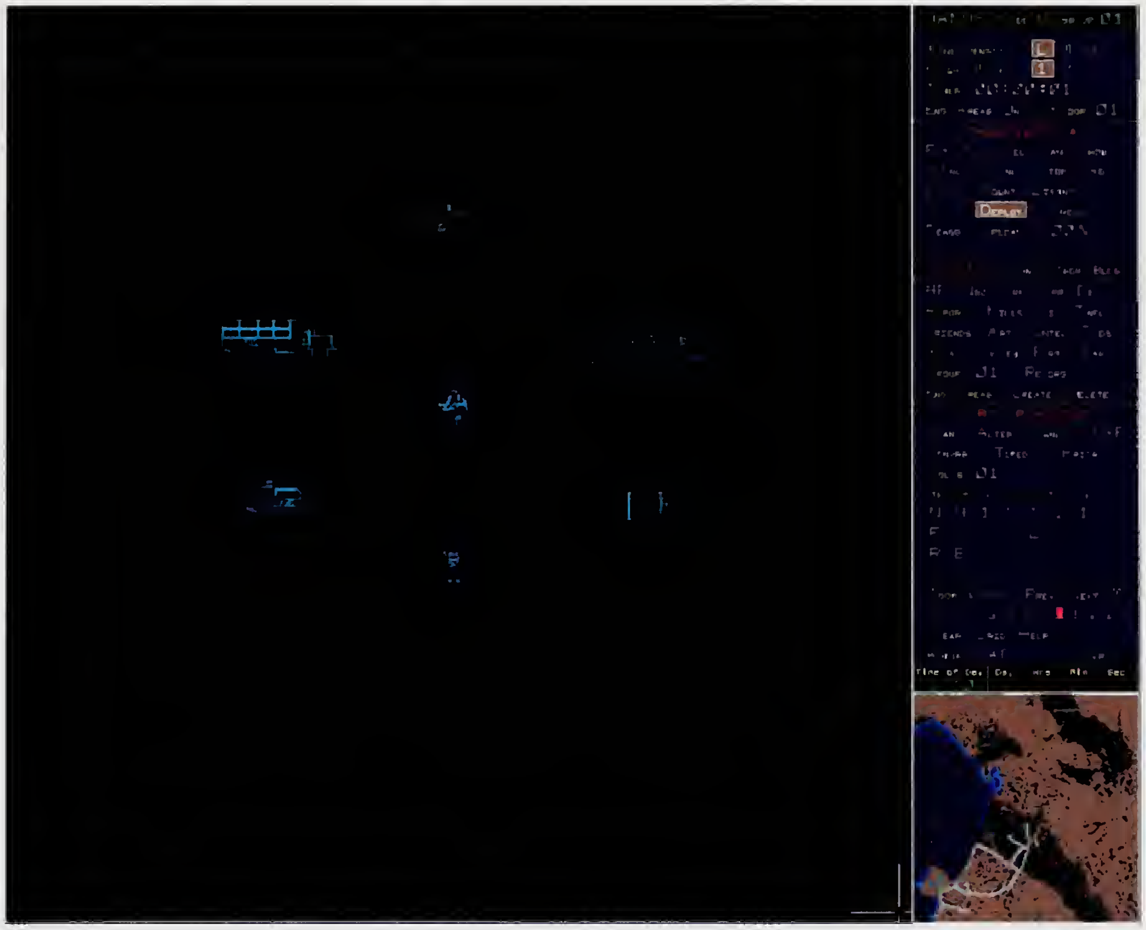

Figure A6. Modeled Entities' Icons

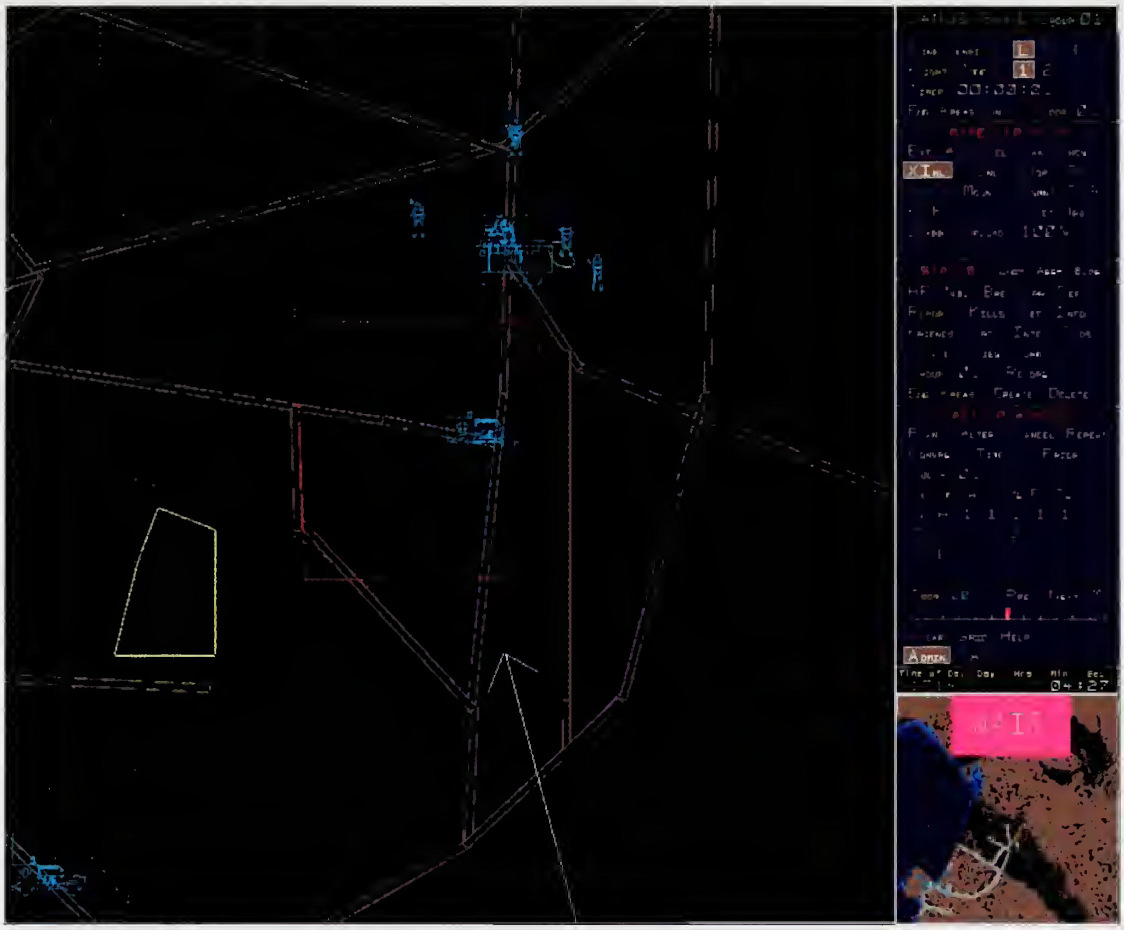

Figure A7. View of Area at H+4 Minutes

Figure A8. Ambulance Enroute to CHOMP

Figure A9. Victims Unloaded at CHOMP

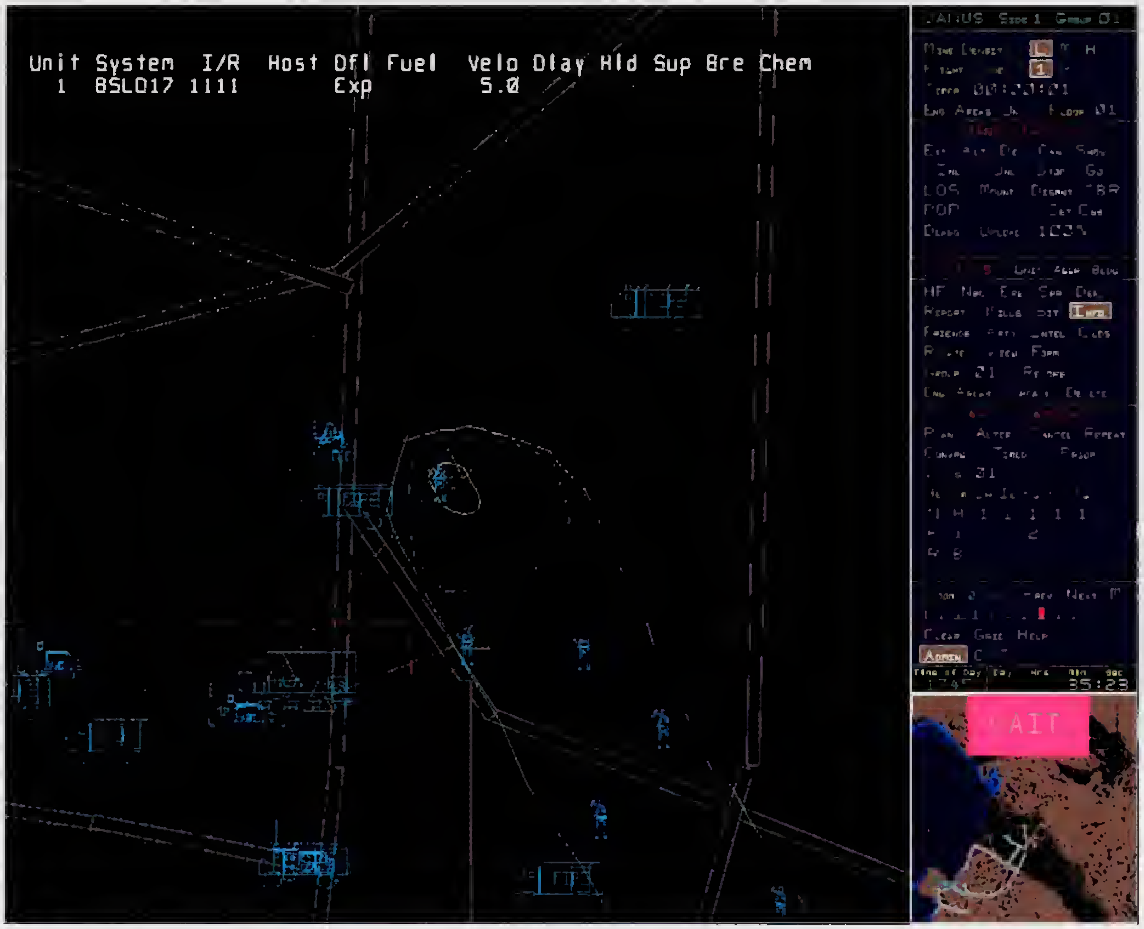

Figure A10. Victims Moving to Decon Site

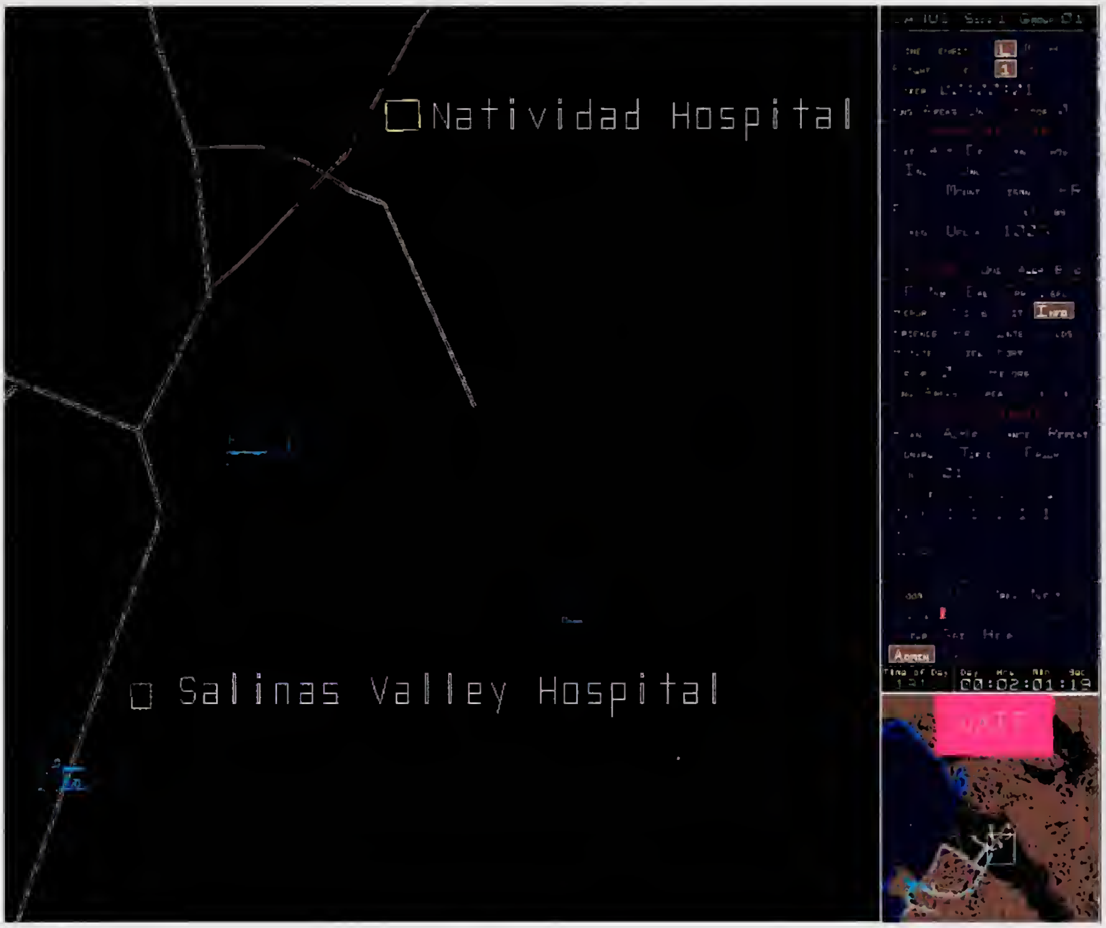

Figure A11. Ambulance Enroute to SVMH

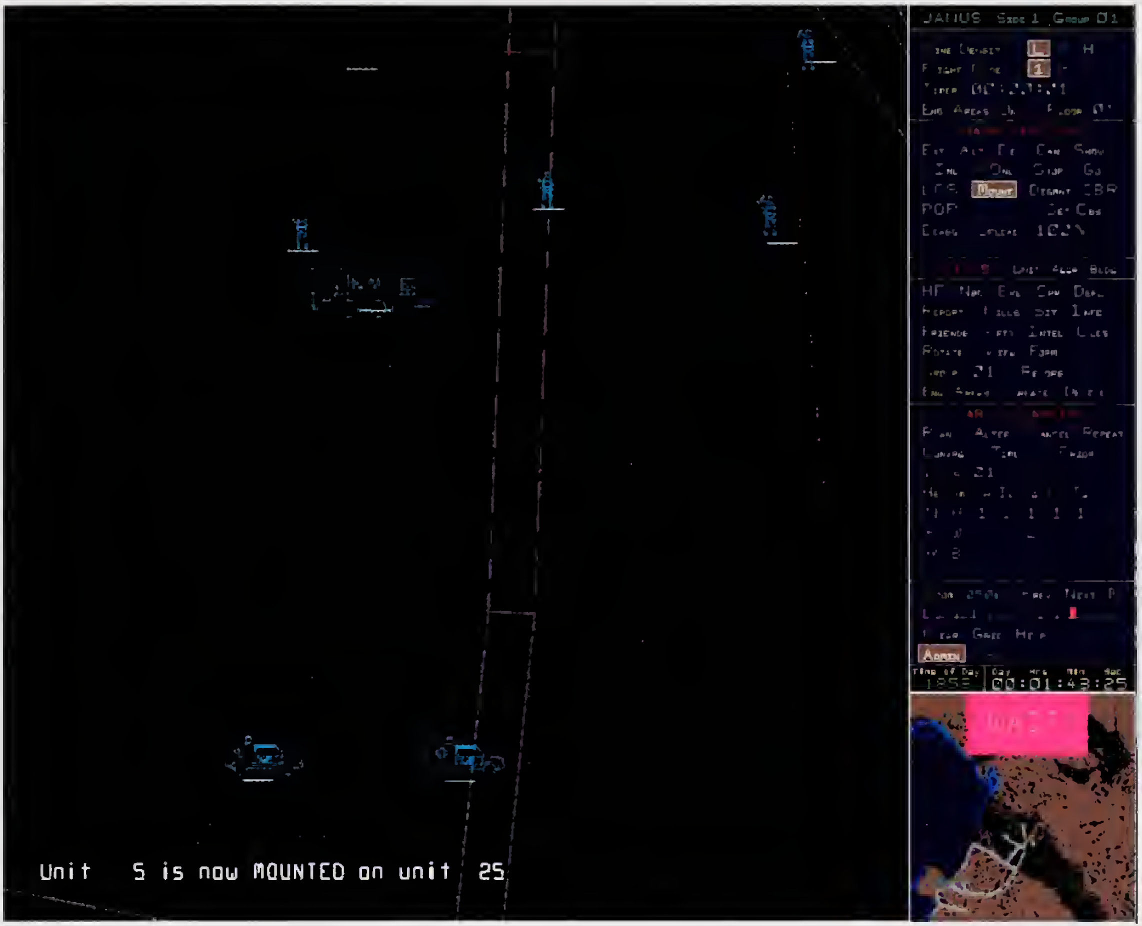

Figure A12. Victims Mounted in Ambulance

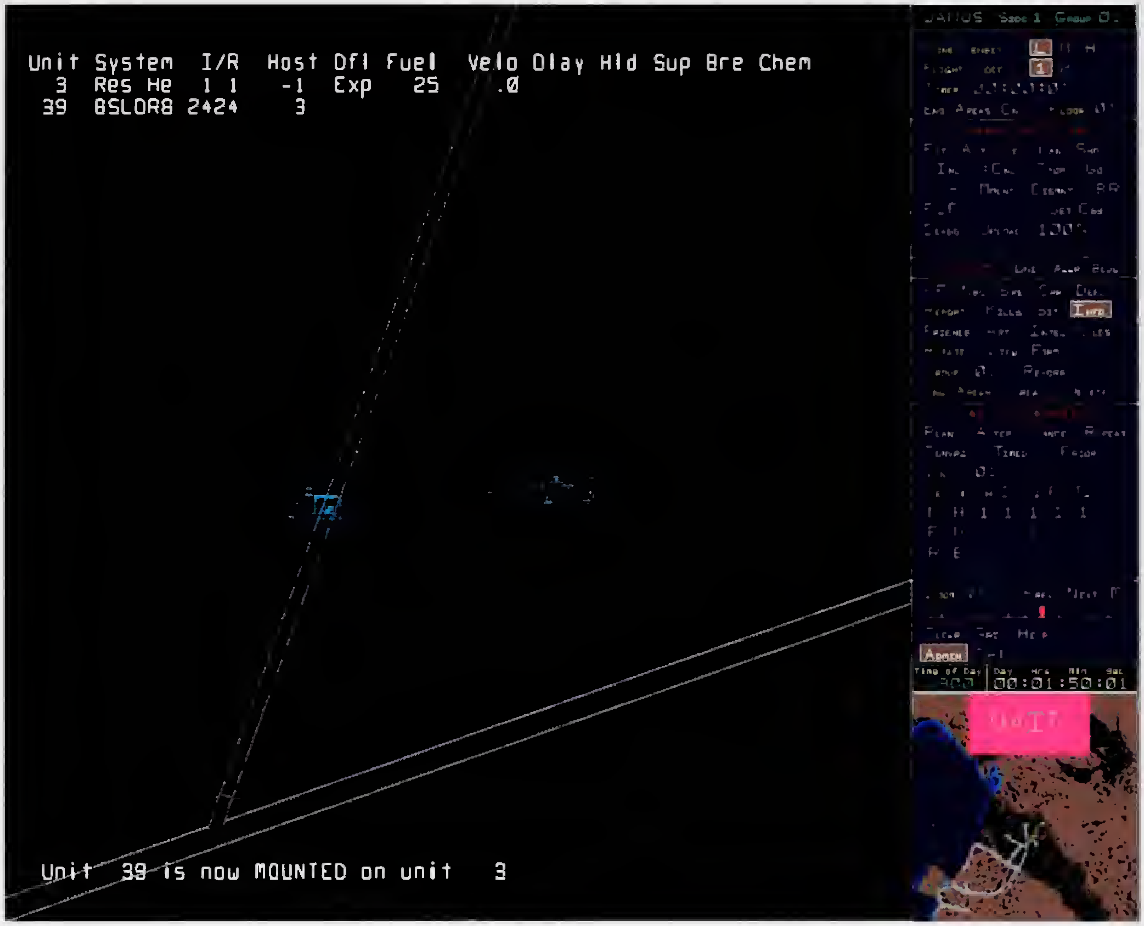

Figure A13. Helicopter Loading Victims

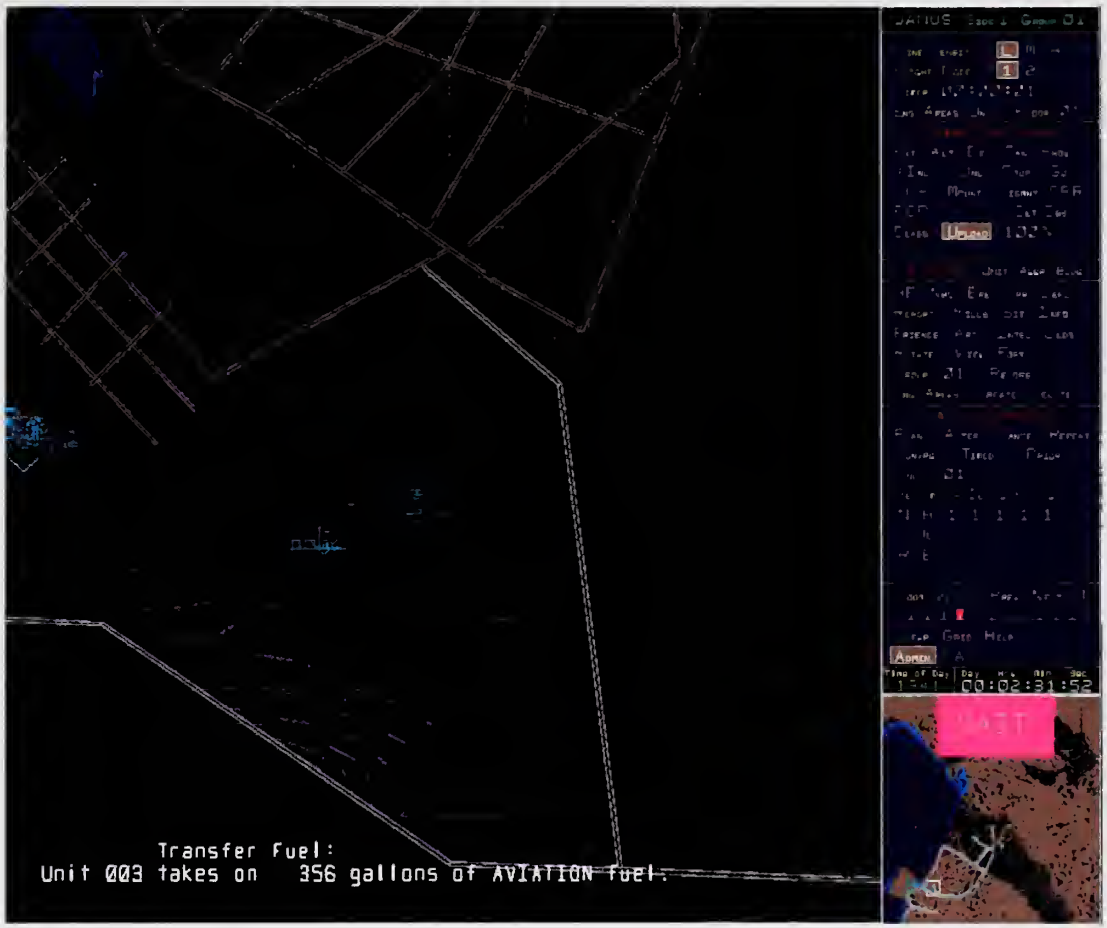

Figure A14. Helicopter Refueling

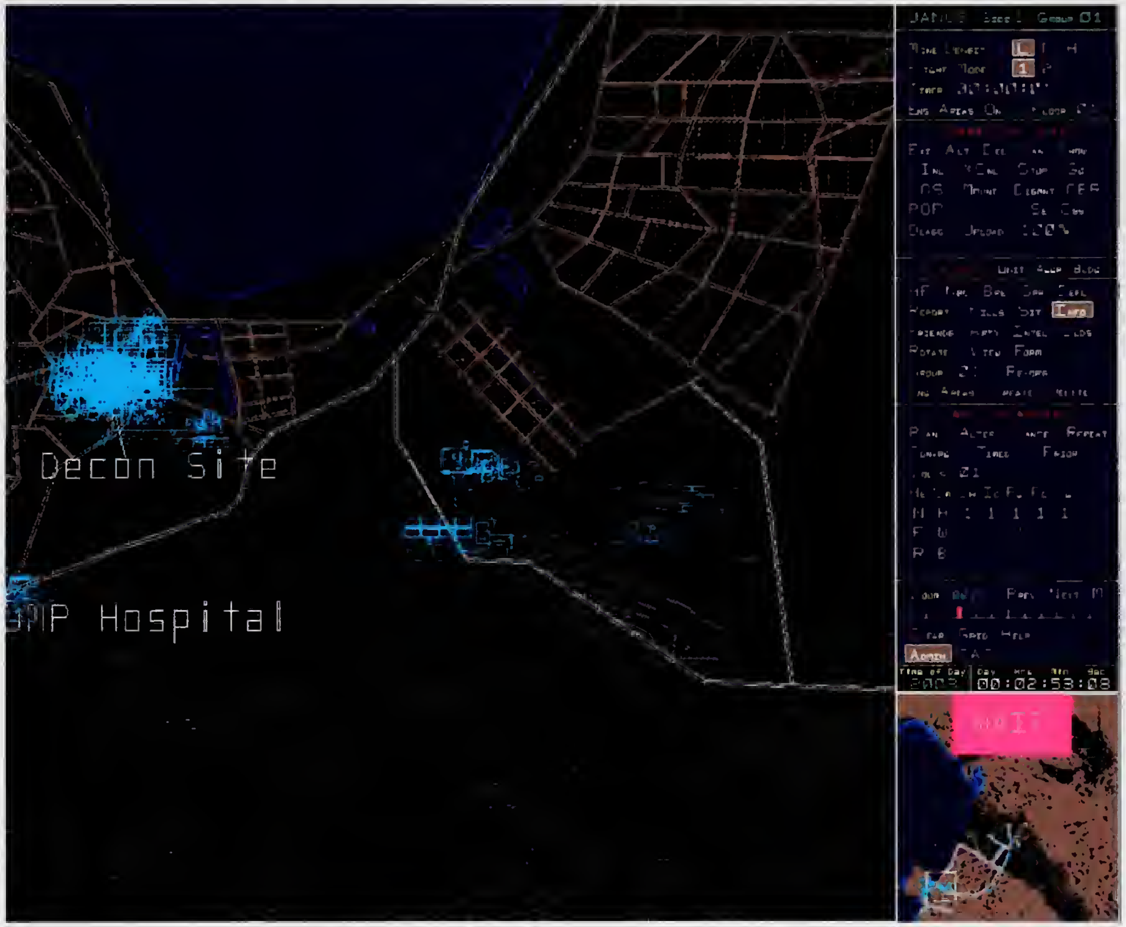

Figure A15. Bus Enroute to NMH

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APPENDIX B. REVIEW OF MODEL

Dr. Russell C. Coile, Disaster Coordinator/Emergency Program Manager of Pacific Grove, California provided the author with the following comments about the simulation and the conclusions and recommendations of this thesis after reviewing the model on May 27, 1999.

1. Scenario Overview - page 13. The estimated values in Table 1 seem reasonable considering the assumption of "ideal performance". It should be realized that putting on and wearing HAZMAT Level A protection suits might slow all operations down.

2. Contaminated area - "For this simulation the contaminated area is known precisely (page 16). In actual operations, the Fire Department's HAZMAT team will use an unclassified plume prediction computer program called "Cameo" which may not be as accurate as the HPAC program. Dr. Coile does not know how long it would take the HAZMAT team to get meteorological data and run the Cameo program.

3. Parameters - page 26. Estimated parameters seem reasonable. However, a number of actual factors might degrade these estimates. For example, travel times to hospitals may be longer if people hear the radio about

"terrorists" and traffic jams build up. There was a classic case in Richmond, California a few years ago when 22,000 people stormed hospitals trying to get into the emergency rooms after a chemical accident. (Approximately 57 people were actually hospitalized.) Also, decontamination may take longer than estimated. More firefighters may be required to relieve the initial ones suited up in HAZMAT gear, etc.

4. Assumptions - page 30. Seem reasonable, but similar cautions about the optimism should be raised.

5. Simulation - page 33. The Janus model with digitized terrain and icons gives an excellent graphical representation of the events.

6. Graphical and statistical analysis of data - page 45. The measures of effectiveness and results seem sensible.

7. Conclusions and recommendations - page 69. The conclusions and recommendations seem appropriate and supported by the data and analysis.

8. Overall comment. The model seems excellent. The Pacific Grove Fire Department is looking forward to an opportunity in the future to use the model to explore various factors which might result in more effective local response to terrorist attacks using weapons of mass destruction.

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